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Air Pollutant Emission Factors for Military and Civil Aircraft

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FOREWORD

When fuels are burned to extract their energy, the related pollutional impacts on our environment often require that new and increasingly more efficient pollution prevention and control methods be used. Development of such methods requires reliable information on sources.

This report examines one aspect of the transportation industry contribution to fuel combustion sources, namely aircraft engine emissions. The report presents in one place a compilation of existing data from several sources. The compilation can be used by regulatory officials and air quality planners, as well as by editors of forthcoming editions of USEPA compilations of emission factors.

For further information, contact the Air Management Technology Branch, Monitoring and Data Analysis Division, Office of Air Quality Planning and Standards.

ABSTRACT

Using data supplied by the U.S. Navy, U.S. Air Force, USEPA Office of Mobile Source Air Pollution Control, as well as published information, tables of military aircraft, fuel characteristics, aircraft classifications, military and civil times in mode, engine modal emission rates, and aircraft emission factors per landing-takeoff cycle are calculated and compiled. The data encompass 59 engines and 89 aircraft. Additional discussion includes information related to benzo[a]pyrene emissions and to hydrocarbon (volatile organic) emission with potential to produce photochemical oxidant.

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1. INTRODUCTION

Federal, state and local government environmental officials concerned with air quality planning and standards require reliable emission factor data for emission inventory calculations. This is true also for various public and private sector personnel performing site-specific environmental impact analyses related to proposed and on-going developments.

For these persons, the USEPA document "Compilation of Air Pollutant Emission Factors (AP-42)" (Ref. 1) has become a standard tool. For AP-42 to remain a useful document, periodic updating and occasional improvements in the quality and useful detail of its tables are necessary.

The AP-42 Section 3.2.1: "Off-Highway, Mobile Sources-Aircraft" received its last update in April 1973. Since that time, great improvements have been made in the quality and volume of available aircraft engine emission data. This is particularly true for military aircraft. Furthermore, there have been significant changes in the composition of the U.S. military aircraft inventory since 1973.

This report is intended to be a background document to support a new edition of Section 3.2.1 of AP-42. It contains a greater volume of detailed information than that which will appear in AP-42. This will permit an interested reader: (a) to calculate aircraft emission factors for some aircraft not included therein; (b) to appreciate the quantitative variations arising from different selections of engine and operating parameters; and (c) to appraise the validity of the data presented in AP-42.

The bulk of this report is concerned with military aircraft. Recent data supplied by the USEPA Office of Mobile Source Air Pollution Control (Ref. 2) are included in order to permit this document to serve as background for both civil and military portions of Section 3.2.1 of AP-42.

2. FLEET STATISTICS

Current military aircraft inventories are not normally released in documents of this type. Historical production data and older inventory data are irrelevant to current air quality assessments, and these are excluded. Inventory compositions at specific military and joint-use metropolitan airports vary with procurements and mission assignments, and compilation of these data would be outside the scope of this report.

By contrast, commercial carrier fleet summaries are easily available. Table 2-1 was assembled from published data (Refs. 3, 4 and 5) as described in the footnote in order to aid selection of aircraft for inclusion in this report. Such data may be used to judge the national significance of particular aircraft, but are irrelevant to local conditions.

Many of the aircraft listed in Table 2-1 see widespread or even predominant use in general aviation. No attempt was made to assemble use statistics for aircraft in general aviation service.

TABLE 2-1. FIXED WING AIRCRAFT IN COMMERCIAL CARRIER SERVICE – 1977 (REF. 3, 4, 5)*

Jets		Turboprops		Piston	
Model	No.	Model	No.	Model	No.
727	843	CV 580	68	Cessna Twins	40
DC-8	340	Twin Otter	66	Heron	31
DC-9	295	Beech 99	52	DC-3	28
707	256	F22/FH227	39	Piper Twins	25
737	166	Electra	28	Cessna Singles	15
DC-10	130	YS-11	21	Islander	12
747	109	Goose	20	Martin 404	12
L1011	82	Metroliner	19	Misc.	39
Falcon	32	Hercules	15		
BAC-111	30	CV 600/640	12		
720	18	Misc.	26		

*"Commercial Carrier Service" includes all scheduled and charter passenger and freight service lines which could be identified as operating wholly or substantially within the 50 states. Categories include: domestic trunk, regional and local service, commuter, scheduled intrastate, and miscellaneous (including charter). Data are as reported in May 1977.

3. COMPOSITION OF ENGINE EMISSIONS

3.1 CRITERIA POLLUTANTS

Tables of air pollutant emission factors normally report carbon monoxide (CO), oxides of nitrogen (NO_x reported as NO_2), hydrocarbons (reported as CH_4), oxides of sulfur (SO_x and H_2SO_4 , reported as SO_2), and particulates when available or calculable. All SO_x data were calculated from engine fuel consumption rates ("fuel rates") by material balance, assuming complete conversion of sulfur to SO_x. Within the precision claimed, this may be correct. Nevertheless, data for SO_x should be regarded as worst-case figures. The method of calculation is described in the footnotes to Tables 5-1 and 5-2. Fuel composition and specifications are discussed in Section 3.4.

3.2 'HYDROCARBON' (VOLATILE ORGANIC) CONSTITUENTS

In order to assess the impact of airport operations upon the local formation of photochemical smog (for which a National Ambient Air Quality Standard exists), it is necessary to know the composition of the "total hydrocarbon" fraction of aircraft emissions. In this context, "hydrocarbon" is more properly referred to as volatile organic and includes, for example, aldehydes. Insufficient specific detail is known on the subject. Trijoinis and Arledge (Ref. 6) have reviewed the available data, have made some working assumptions based on their review, and have attempted to quantitatively classify engine emissions into a 5-group reactivity scheme. Their ratings are based on the oxidant production potential of organics in each class, as determined experimentally by EPA (Ref. 7) in smog chamber tests, and upon data published by Groth and Robertson (Ref. 8) and by Chase and Hurn (Ref. 9). The reader may consult Ref. 6 for more detailed discussions. The Trijonis and Arledge results are reproduced in Tables 3-1 and 3-2, and in more detail in Appendix A.

The working assumptions implicit in these tables are that the composition of the hydrocarbon fraction is independent of engine type and of fuel composition. The first is unproved; the second is unlikely. Further, Table 3-2 was derived from Table 3-1 using assumptions and methods not described by the authors in Ref. 6. It seems constructive to present the Trijonis and Arledge results, so that the reader may apply them to subsequent data in this report as and if useful and applicable.

Methods of reporting total hydrocarbon (THC), i.e., volatile organic, concentration vary and are not always specified. The flame ionization

TABLE 3-1. DISTRIBUTION OF ORGANICS BY NUMBER OF CARBON ATOMS – TURBINE ENGINES (REFS. 6 AND 9).

Carbon Number	Mole % of Total Organics					
	Idle		Takeoff		Approach	
1	2	11	3	3	3	5
2	6		0		1	
3	3		0		1	
4	2	11	1	5	1	5
5	2		3		2	
6	7		1		2	
7	8	38	1	33	7	33
8	7		13		14	
9	11		6		2	
10	12		13		10	
11	9	40	5	59*	5	57
12	8		4		4	
13	7		4		3	
14	5		5		4	
15	3		3		4	
16	2		3		3	
17	1		4		4	
18	1		3		3	
19+	4		30		27	
Weight % Aldehydes relative to total hydrocarbons	10%		30%		57%	

*Inconsistency in source from which quoted.

TABLE 3-2. APPROXIMATE DISTRIBUTION BY ORGANIC TYPE IN CARBON NUMBER CATEGORIES – TURBINE ENGINES (REF. 6).

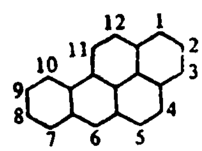
Carbon Number Category	Type of Compounds	Taxi-Idle Mode	Takeoff Mode	Approach Mode
1-3	Paraffins	7	2	1
	Acetylene	1	0	0
	Olefins	2	0	1
	Aldehydes	1	1	3
4-6	Paraffins	7	2	1
	Olefins	2	1	0
	Aldehydes	1	2	3
	Benzene	1	0	1
7-10	Paraffins	19	17	17
	Olefins	7	7	3
	Aldehydes	4	3	7
	n- & sec- alkylbenzenes	4	3	3
	Dialkylbenzene	4	3	3
11+	Paraffins	12	6	23
	Olefins	8	12	6
	Aldehydes	4	17	17
	tert-alkylbenzenes	4	6	0
	n- & sec- alkylbenzenes	4	6	5
	Dialkylbenzenes	4	6	6
	Tri- and tetra-alkyl-benzenes	4	6	0
		100%	100%	100%

detector commonly used to measure THC is basically a carbon counter. To calculate a mass emission rate, kg/hr, an assumption must be made as to x in the equivalent formula (CH_x) of the exhaust gas. Historically, THC has often been expressed as methane (CH_4) equivalent. It is our understanding that all Dept. of Defense supplied and all USEPA supplied data (Ref. 2) are expressed as CH_4 equivalent, except for USEPA data for General Electric engines. These are expressed as $CH_{1.8}$ (the fuel value). The latter can be converted to methane equivalent by multiplying by 1.159.

The reader must be aware, therefore, that there may be uncertainties of about 14% in the reporting basis of volatile organics. However, to place this in perspective: sampling and analysis errors, uncertainties and variations in engine power levels, variations in aircraft operating procedures, and even imprecisions in dispersion modeling can be sustantial. Their combined effects may be considerably greater than uncertainties in the reporting base for THC emissions.

3.3 BENZO[a]PYRENE

Although the term benzo[a]pyrene (BaP) is now often used loosely for the whole group of polynuclear (polycyclic) aromatic hydrocarbons and their derivatives, we refer here specifically to the substance whose structural formula is:



BaP is rated as among the most carcinogenic chemical compounds to which man is exposed (Refs. 11 and 12). In populous regions of the U.S., the major sources are known to be residential hand-stoked coal and wood combustion, waste combustion, and coke production (150 to 600 tons/yr). In the second rank are mobile sources (10 to 20 ton/yr), including automotive.

Apparently aircraft piston and turbine engines have not been surveyed (Ref. 11). However, a priori considerations force us to believe that turbine engines must emit BaP. As a general rule, BaP production occurs (Ref. 11):

- In any combustion producing CO
- In any process producing gray or black smoke
- In any combustion or pyrolysis at $\geq$ 500 F known to be oxygen deficient ("substoichiometric" in oxygen).

Some members of the National Research Council Committee on Biologic Effects of Atmospheric Pollutants (Ref. 12) state that aircraft probably produce annually in the order of twice as much BaP as gasoline powered automobiles – in other words, approximately 20 tons per year.

Piston engine aircraft, which lack emission control devices, may have emission factors approximating those of uncontrolled postwar cars, namely approximately 170 μg BaP per gallon of fuel consumed. Reference 11 contains a quantitative discussion of the dramatic improvements in BaP emission factors resulting from emission controls, and of the effect of engine age upon BaP releases.

3.4 FUEL COMPOSITION

Fuel contaminants, additives, and physical characteristics can affect combustion processes and emission rates. Some relevant research has been reported. Tables 3-3, 3-4 and 3-5 contain some incomplete data on specifications, test data, and national averages for turbine engine fuel and aviation gasoline.

Aside from matters related to performance and reliability, fuel modifications or substitutions impact emissions and involve trade-offs with other non-environmental goals. Figure 3-1, due to Grobman, et al., (Ref. 17), emphasizes some of these tradeoffs.

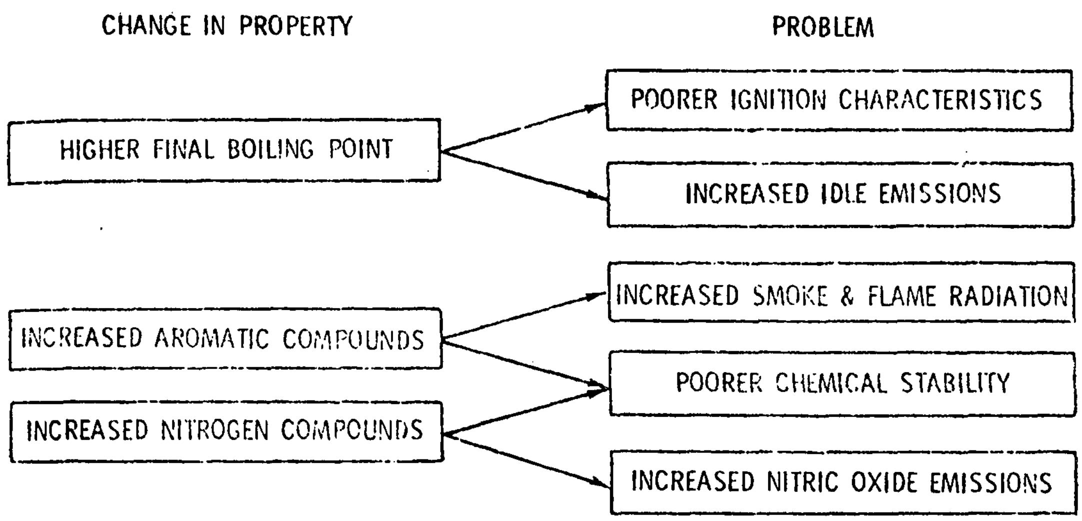


Figure 3-1. Problems associated with altered fuel characteristics (Ref. 17).

TABLE 3-3. SPECIFICATIONS FOR RELEVANT PROPERTIES OF JET FUELS (REFS. 13, 14, 15 AND 31)

Property	JP-4 MILSPEC MIL-T-5624	JP-4 Representative Actual	JP-5 MILSPEC MIL-T-5624	JP-5 Representative Actual	Jet A ASTM D-1655	Jet B ASTM D-1655
Composition						
Hydrogen, wt%	—	14.31	—	13.79		
Sulfur, wt% (max)	0.4	0.072			0.3	0.3
Mercaptan sulfur, wt% (max)	0.001		0.001		0.003	0.003
Aromatics, vol% (max)	25.0	14.8			20.0	20.0
Olefins, vol% (max)	5.0	0.6	5.0		5.0	5.0
Fuel System Icing Inhibitor, vol% (min/max)	0.10/0.15					
Anti-oxidants (Blended Separately or in Combination) (max)	9.1 g/100 gal					
2,6 – di-tert-butylphenol	75% min					
2,6 – di-tert-butyl-4-methylphenol	—					
2,4 – dimethyl-6-tert-butyl phenol tri-tert-butylphenols	25% max					
N,N' – diisopropyl-p-phenylenediamine	—					
N,N' – di-sec-butyl-p-phenylenediamine	—					
Heat of Combustion, Btu/lb (min)	18,400	18,622	18,300	18,444	18,400	18,400
Smoke Point (min)	—	28.0				
ASTM Distillation:						
Initial Boiling Point, °F	—	164	—	330	—	—
10% max °F	—	202	400	371	400	—
20% max °F	290	218	—	384	—	290
50% max °F	370	266	—	407	450	370
90% max °F	470	393	—	450	—	470
Final Boiling Point, °F (max)	—	470	550	480	550	—

TABLE 3-4. 1976 U.S. NATIONAL DATA FOR AVIATION TURBINE ENGINE FUELS (REF. 13)

	Jet A	Jet B	JP4	JP5
No. Samples Analyzed	65	5	33	8
S, wt%	0.60	0.041	0.042	0.059
Mercaptan, wt%	0.0009	0.0005	0.0005	0.0004
Olefins, vol%	1.1	0.9	0.9	0.8
Aromatics, vol%	17.0	10.6	11.2	16.9

TABLE 3-5. COMPOSITION OF AVIATION GASOLINE (REFS. 14, 16)

	Mil Spec[a]	1963 Measurements
S, wt%	0.05	$\leq$ 0.01
Aromatics		
80/87	—	
100/130	—	
115/145 min	5.0	

[a]MIL-G-5572E Amend. 2, May 1975.

Figure 3-2 shows the relationship between visible emissions (reported as SAE smoke number) and hydrogen content of the fuel, which in turn varies approximately inversely as the aromatics content (Ref. 17). NO_x emissions are not very sensitive to fuel nitrogen content, since most NO_x is produced by oxidation of atmospheric nitrogen in combustion air. Grobman, et al., (Ref. 17) give an example in which an 80-fold increase in fuel nitrogen caused an 18% increase in NO_x emission. Engine operating and design parameters (e.g., fuel-air ratio and inlet temperature) have more affect on NO_x production.

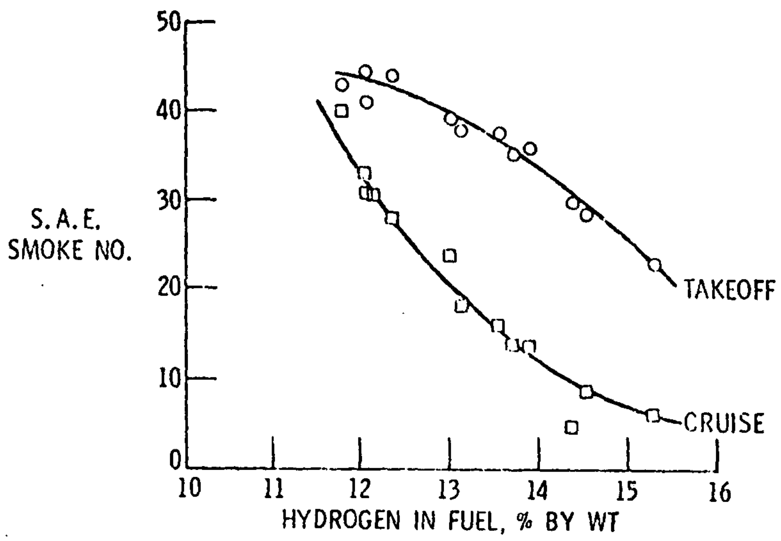


Figure 3-2. Effect of fuel hydrogen content upon visible emissions (Ref. 17).

Volatile organic emissions result from several airport operations apart from engine operation. Examples are: fuel transfer, spillage, storage, operation of auxiliary power units, and engine maintenance. Fuel volatility not only effects engine performance, but also fugitive emissions. Figure 3-3 presents a schematic comparison of fuel volatility, expressed as boiling ranges.

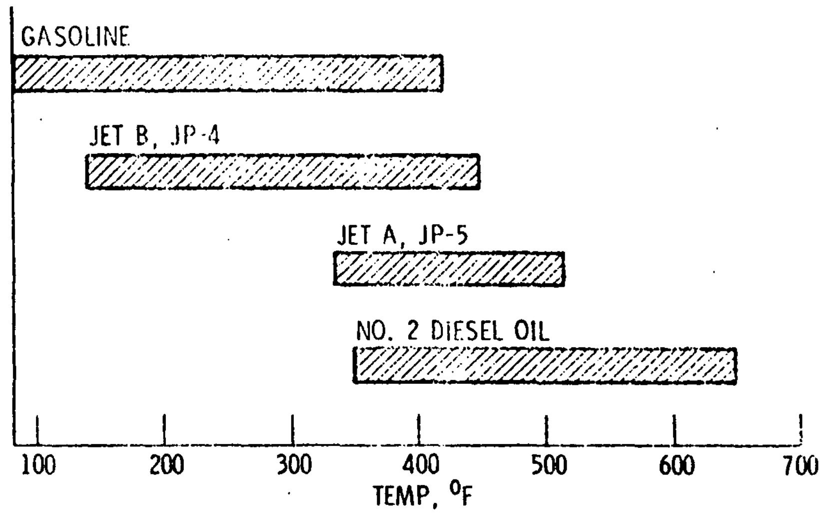


Figure 3-3. Boiling range of various petroleum products (Ref. 17)

4. DEVELOPMENT OF THE EMISSION TABLES

4.1 SELECTION AND CULLING OF DATA

Civil aircraft emission data reported in later sections were received from the USEPA Office of Mobile Source Air Pollution Control, Ann Arbor, Mich., (Ref. 2, 20). On the basis of the data reported earlier in Table 2-1, the BAC-111 has been added to the Commercial Carrier Jet Category, and the entire category of Air Carrier Turboprops has been added. The Dassault Falcon 20 has been added to the General Aviation category. Several more aircraft definitely deserved listing on the basis of frequency of use; however, engine emission data were not available. Two examples are the venerable DC-3 and the Martin 404.

Selection of military engines and aircraft was the most time-consuming task in this project. A very large number of distinct engines and aircraft exist, and a very large volume of emissions data are available, principally in the U.S. Navy's emissions data compendium (Ref. 21). The data presented were culled from information on 1000 military aircraft models and variations. Engines surveyed included 82 models and 424 series: 19 models and 181 series of turbojets; 14 models and 38 series of turbofans; 10 models and 45 series of turboprops; 16 models and 54 series of turboshafts; 14 models and 46 series of opposed piston engines; and 9 models and 60 series of radial piston engines.

Emission data were not available for all of these. Further, most aircraft had several alternative engines. Because inventory data were not available, we were not necessarily able to select the most common model/series engine for each model/variation of aircraft. Frequently we had to be satisfied with listing an engine known to be representative, if not necessarily the most commonly installed in a given aircraft.

To cull the data we used 5 x 8 in. double-row edge-notch cards designed for manual sorting.

Aircraft cards were entered with:

Model/Variation
Popular Name
Mission
Number of Engines
Engine Type
Engine Model/Series

Service Using
Whether Fixed Wing or Rotary
Whether Emission Data were Available.

These cards were edge-notch coded for each option of mission, engine, etc.

Engine cards contained entries for:

Type
Model/Series
Aircraft Types on Which Used
Service in Which Used
Whether Emission Data were Available.

Using these sorting cards, we were able to select a list of aircraft model/variations with engine model/series representative of those aircraft, and requiring a minimum number of engines for compilation in the modal emission rate tables (cf., later sections). This list was expanded somewhat to include aircraft variations displaying significantly different emissions characteristics because of engine choice, mission, service, characteristics, etc. An example would be the inclusion of both the B52G and B52H bombers, and two versions of the A7 Corsair 2 attack aircraft.

The culling process was assisted by our use of several non-military publications (Refs. 22 and 23), in addition to military and civilian experts (Refs. 24 through 30).

Standard annual publications in this field are the Aerospace Forecast and Inventory Issue, "Aviation Week and Space Technology," (Ref. 22) and the huge Jane's All the Worlds Aircraft (Ref. 23).

4.2 MILITARY AIRCRAFT CLASSIFICATION

The result of the sorting discussed in the preceding section is displayed in Table 4-1. Entries are largely self-explanatory, except perhaps for the power plant type designation. The following discussion is largely from Masser (Ref. 1).

Aircraft engines are of two major categories: reciprocating (piston) and gas turbine.

The basic element in the aircraft piston engine is the combustion chamber, or cylinder, in which mixtures of fuel and air are burned and from which energy is extracted through a piston and crank mechanism that drives a propeller. The majority of aircraft piston engines have two or more cylinders and are generally classified according to their cylinder arrangement — either "opposed" or "radial." Opposed engines are installed in most light or utility aircraft; radial engines are used mainly in large transport aircraft. Almost no single-row inline or V-engines are used in current aircraft. The gas turbine engine in general

TABLE 4-1. MILITARY AIRCRAFT CLASSIFICATIONS (REFS. 21, 22, 23)

Aircraft Mission (Class)	DOD Designation	Popular Name	Manufacturer[a]	Service	Power Plant: No. & Type[b]	Mfg.[a]	Designation	Afterburner?	Other Versions and Related Military Aircraft Included and Civil Equivalents
			FIXED WING				TURBINE		
Attack	A-4	Skyhawk	McD-Doug	USN, USMC	1 TJ	P&W	J52, J65		TA-4
	A-6	Intruder	Grumman	USN	2 TJ	P&W	J52		EA-6, KA-6
	A-7	Corsair 2	Vought	USN	1 TF	All, P&W	TF 41, TF30	No	TA7
	AV-8A	Harrier	Hawk-Sid	USMC	1 TF	RR	F402	No	TAV8
	A-10	--------	Fairch-Rep	USAF	2 TF	GE	TF34	No	
	A37	Dragonfly	Cessna	USAF	2 TJ	GE, Con.	J85, J69	No	
Bomber	B-52 C-G	Stratofortress	Boeing	USAF	8 TJ	P&W	J57	No	
	B-52H	Stratofortress	Boeing	USAF	8 TF	P&W	TF33	No	
Fighter	F-4	Phantom 2	McD-Doug	USAF, USN	2 TJ	GE	J79	Yes	RF-4
	F-5	Freedom Fighter (Tiger 2)	Northrop	USAF	2 TJ	GE	J85	Yes	
	F-8	Crusader	Vought	ANG	1 TJ	P&W	J57		TF-8, RF-8
	F-14	Tomcat	Grumman	USN	2 TF	P&W	TF30, F401	Yes	
	F-15A	Eagle	McD-Doug	USAF	2 TF	P&W	F100	Yes	TF 15
	F-16	--------	GD/FW	USAF	1 TF	P&W	F100	Yes	
	F-100	Super Sabre	No. Amer.	ANG	1 TJ	P&W	J57	Yes	
	F-106	Delta Dart	GD/Convair	USAF	1 TJ	P&W	J75	Yes	
	F-111	--------	GD/FW	USAF	2 TF	P&W	TF30	Yes	FB-111, EF-111A
	F-18	Hornet	Northrop & McD-Doug	USN, USMC	2 TF	GE	F404		YF-17, TF-18
Cargo/Tanker/ Transport	C-2	Greyhound	Grumman	USN	2 TP	All	T56	No	E-2
	C-5A	Galaxy	GELAC	USAF	4 TF	GE	TF39	No	
	C-9	Nightingale (Skytrain 2)	McD-Doug	USAF, USN	2 TF	P&W	JT8D	No	VC-9; (DC-9 Equiv.) (Super King Air 200)
	C-12	Huron	Beech	USAF, USA	2 TP	PWC	PT6A	No	
	C-130	Hercules	GELAC	USAF, USN, USCG	4 TP	All	T56	No	DC, HC, RC, EC, AC, WC Versions

[a] *Abbreviations:* All – Detroit Diesel Allison Division of General Motors; CAE – Teledyne CAE (Continental); CALAC – Lockheed-California; Con – Continental; Fairch-Rep – Fairchild Republic; GA – Garrett AiResearch; GD/FW – General Dynamics, Ft. Worth; GE – General Electric; GELAC – Lockheed-Georgia; Hawk-Sid – Hawker Siddeley (UK); Helio/GA – Helio General Aircraft; Lyc – Lycoming; McD-Doug – McDonnell Douglas; P&W – Pratt & Whitney; PWC – Pratt & Whitney Aircraft of Canada; RI/Columbus – Rockwell International, Columbus; RI/GA – Rockwell International, General Aviation; RR – Rolls Royce; Wr – Curtiss Wright.

[b] TJ – Turbojet; TF – Turbofan; TP – Turboprop; TS – Turboshaft; R – Reciprocating (Piston), Radial; O – Reciprocating (Piston), Opposed.

TABLE 4-1. (CONTINUED)

Aircraft Mission (Class)	DOD Designation	Popular Name	Manufacturer[a]	Service	Power Plant No. & Type[b]	Power Plant Mfg.[a]	Power Plant Designation	Power Plant Afterburner?	Other Versions and Related Military Aircraft Included and Civil Equivalents
			FIXED WING		TURBINE				
Cargo/Tanker/ Transport	KC-135	Stratotanker	Boeing	USAF	4 TJ	P&W	J57	No	C, EC, RC Versions
	C-140	Jet Star	GELAC	USAF, USN	4 TJ	P&W	J60	No	VC-140
	C-141	Starlifter	GELAC	USAF	4 TF	P&W	TF33	No	
Trainer	T-2	Buckeye	RI/Columbus	USN	2 TJ	GE	J85, J34, J60		
	T-34C	Turbo Mentor	Beech	USN	1 TP	PWC	PT6A	No	(See T34 A/B Mentor)
	T-37	Tweet	Cessna	USAF	2 TJ	CAE	J69	No	
	T-38	Talon	Northrop	USAF	2 TJ	GE	J85	Yes	
	T-39	Sabreliner	RI/GA	USAF, USN	2 TJ	P&W	J60	No	CT39
	T-44	--------	Beech	USN	2 TP	PWC	PT6A	No	VC6B; (King Air 90)
Observation Patrol/Antisub, Early Warning	OV-1	Mohawk	Grumman	USA	2 TP	Lyc	T53	No	RV-1
	OV-10	Bronco	RI/Columbus	USA	2 TP	GA	T73	No	
	P-3C	Orion	CALAC	USN	4 TP	All	T56	No	(Electra)
	S-3A	Viking	CALAC	USN	2 TF	GE	TF34	No	
	E-2	Hawkeye	Grumman	USN	2 TP	All	T56	No	
	E-3A	AWACS	Boeing	USAF	4 TF	P&W	TF33	No	
Utility	U-21	Ute	Beech	USA	2 TP	PWC	T74, PT6A	No	RU21, (King Air A90, A100)
	AU-23	Peacemaker	Fairchild	USAF	1 TP	GA	TPE331-1	No	
	AU-24	Stallion	Helio/GA	USAF	1 TP	PWC	PT6A	No	

TABLE 4-1. (CONCLUDED)

Aircraft Mission (Class)	DOD Designation	Popular Name	Manufacturer[a]	Service	Power Plant: No. & Type[b]	Mfg.[a]	Designation	Afterburner?	Other Versions and Related Military Aircraft Included and Civil Equivalents
			FIXED WING		PISTON				
Cargo/Tanker/ Transport	C-1	Trader	Grumman	USN	2 R	Wr	R-1820		S-2D
Trainer	T-28	Trojan	RI/Columbus	USN	1 R	Wr	R-1820, 1300		
	T-29	Flying Classroom	CALAC	USN	2 R	P&W	R-2800		
	T-34	Mentor	Beech	USN	1 O	Con	0-470		(See T-34C Turbomentor)
	T-41	Mescelero	Cessna	USA	1 O	Con	IO-360		(Cessna 172-Skyhawk)
	T-42	Cochise	Beech	USA	1 O	Con	IO-470		(Baron B-55)
Observation	O-1	Bird Dog	Cessna	USA	1 O	Con	O-470		
	O-2	--------	Cessna	USAF	2 O	Con	IO-360		
	S-2	Tracker	Grumman	USN	2 R	Wr	R-1820		E1B, C1A
Utility	U-4	Aero Commander	RI/GA	USA	2 O	Lyc	GSO-480		U-9
	U-8	Seminole	Beech	USA	2 O	Lyc	O-480, IGSO-480		(Twin Bonanza E-50; Queen Air 65)
	U-10	Courier	Helio/GA	USA	1 O	Lyc	GO-480		
			ROTARY WING						
Utility	UH-1H	Iroquois ("Huey")	Bell Heli	USA, USN	1 TS	Lyc, GE	T53, T58		UH-1A/B/C/D/E/F/L; HH-1H, K
Utility	UH-1N	Twin Huey	Bell Heli	USAF, USN, USMC	2 TS	PWC	T400		
Attack	AH-1G	Hueycobra	Bell Heli	USN	1 TS	Lyc, PWC	T53, T400		AH1J, UH-1G, TH-1G
Antisub	SH-2D/F	Seasprite	Kaman	USN	2 TS	GE	T58		(UH-2A/B/C have one T58)
Search/Rescue	HH-3	Sea King "Jolly Green Giant"	Sikorsky	USAF, USN, USCG	2 TS	GE	T58		CH, RH, SH, UH, VH versions
Observation	OH-6A	Cayuse	Hughes Heli	USA	1 TS	All	T63		
Search/Rescue	HH-43	Huskie "Mixmaster"	Kaman	USAF	1 TS	Lyc	T53		UH-46
Cargo	CH-46	Sea Knight	Boeing Vertol	USA, USN	2 TS	GE	T58		
Cargo	CH-47	Chinook	Boeing Vertol	USA	2 TS	Lyc	T55		
Search/Rescue	HH-52	--------	Sikorsky	USN	1 TS	GE	T58		
Cargo	CH-53	Sea Stallion	Sikorsky	USAF, USN	2 TS	GE	T64		RH, VH versions
Search/Rescue	HH-53	Super Jolly	Sikorsky	USAF	2 TS	GE	T64		
Cargo	CH-54	Tarhe	Sikorsky	USA	2 TS	P&W	JFTD-12A		
Trainer	TH-55	Osage	Hughes	USA	1 O	Con	H10-360		(Hughes 300)
Trainer	TH-57	Sea Ranger	Bell Heli	USN	1 TS	All	250-C18		
Observer	OH-58	Kiowa	Bell Heli	USA	1 TS	All	T63		

consists of a compressor, a combustion chamber, and a turbine. Air entering the forward end of the engine is compressed and then heated by burning fuel in the combustion chamber. The major portion of the energy in the heated air stream is used for aircraft propulsion. Part of the energy is expended in driving the turbine, which in turn drives the compressor. Turbofan and turboprop or turboshaft engines use energy from the turbine for propulsion; turbojet engines use only the expanding exhaust stream for propulsion. The terms "propjet" and "fanjet" are sometimes used for turboprop and turbofan, respectively.

The fact that a particular aircraft is not listed in Table 4-1 does not imply that emission factors cannot be calculated. It is the <u>engine</u> emissions and the time-in-mode category which determine emissions. If these are known, emission factors can be calculated in the same way that the following tables were developed (cf., Sections 4-3 and 4-4).

Frequently aircraft will be identified by popular name rather than model. Table 4-2 can be used to determine model numbers and representative engines. To select an appropriate time-in-mode category, the aircraft mission must be known. A standardized nomenclature exists for military aircraft (Ref. 21). Deviations from this nomenclature are frequent, however.

Mission Symbol	Mission
A	Attack Aircraft
B	Bomber Aircraft
C	Cargo/Transport Aircraft
D	Director Aircraft
E	Special Electronic Installation Aircraft (Early Warning)
F	Fighter Aircraft
H	Search/Rescue Aircraft
K	Tanker Aircraft
L	Cold Weather Aircraft
N/J	Special Test Aircraft
O	Observation Aircraft
P	Patrol Aircraft
Q	Drone Aircraft
R	Reconnaissance Aircraft
S	Anti-Submarine Aircraft
T	Trainer Aircraft
U	Utility Aircraft
V	Staff Aircraft
W	Weather Aircraft
X	Research Aircraft

<u>Example:</u>

U H - 2 B

Basic Mission Symbol (Utility Aircraft) — U
Type Symbol (Helicopter Type) — H
Design Number (2nd Type Helicopter) — 2
Series Letter (2nd Series) — B

TABLE 4-2. CROSS REFERENCE OF POPULAR OR UNOFFICIAL NAMES WITH MILITARY DESIGNATIONS (REFS. 21, 22, 23, 24)

Popular Names	Model Designation	Basic Engine	Cognizant Service
AAH	YAH-64	T700	Army
Academe	TC-4C	MK529	Navy
Advanced Harrier	AV-8B	RR Pegasus 11	USMC
Aero Commander	U-4/U-9	GO-480	AF
Albatross	HU-16	R-1820	Navy/AF/USCG
AWACS	E-3A	TF33	AF
Aztec	U-11	0-540	Navy
Beaver	U-6	R-985	AF/Army/Navy
Bird Dog	U-1	0-470	Army
Blackbird	SR-71	J58	AF
Bronco	OV-10	T76	AF/Navy
Buckeye	T-2	J34/J60/J85	Navy
Canberra	B-57	J65/TF33	AF
Cargo Master	C-133	T34	AF
Caribou	C-7A	R-2000	AF
Cayuse	OH-6A	T-63	Army
Cheyenne	AH-56A	T64	Army
Chickasaw	H-19	R-1300/1340	AF
Chinook	CH-47	T55	Army
Choctaw	CH-34	R-1820	AF/Army
Chochise	T-42A	IO-470	Army
Cobra	See Hueycobra		USN
Cobra	F-18L	F404	USN
Commando	C-46	R-2800	AF
Constellation	C-121A	R-3350	AF/Navy
Corsair II	A-7	TF41	Navy
Cougar	F-9	J48	Navy
Courier	U-10	GO-480	AF
Crusader	F-8	J57	Navy
Dash	QH-50C	T50	Navy
DC-3	See Sky Train		
Delta Dagger	F-102	J57	AF
Destroyer	RB-66	J71	AF
Dragonfly	A-37B	J85	AF
Eagle	F-15A	F100	AF
Flying Boxcar	C-119	R-3350/4360 & J85	AF
Flying Classroom	T-29	R-2800	AF
Freedom Fighter	F-5	J85	AF
Galaxy	C-5A	TF39	AF
Globemaster	C-124	R-4360	AF
Greyhound	C-2	T56	Navy
Gulfstream I	C-4	MK529	CG
Gulfstream II	VC-11	MK511	CG
Harrier	AV-8A	F-402	Navy
Hawkeye	E-2	T56	Navy
Hercules	C-130	T56	AF/Navy
Huey	See Iroquois		
Hueycobra	AH-1G	T53/400	Army
Huron	C-12A	PT6A	Army/AF
Huskie	H-43	T53	AF/Navy
Hustler	B-58	J70	AF
H-500 Twin	U-5A	O-540	AF
Intruder	A-6	J52	Navy
Invader	A-26	R-2800	AF
Iroquois	UH-1	T53/58/400	Army
Jet Star	C-140	T60	AF/Navy
Jolly Green Giant	HH-3E	T58	AF

TABLE 4-2. CONTINUED

Popular Names	Model Designation	Basic Engine	Cognizant Service
Kiowa	OH-58	T63	Army
Liftmaster	C-118	R-2800	AF/Navy
Mentor	T-34	O-470	AF/Navy
Mescalero	T-41	O-300	Army/AF
Mixmaster	See Huskie		
Mohawk	OV-1	T53	Army
Mojave	CH-37	R-2800	AF/Navy
Navigator	RC-45J/UC-45J	R-985	USN
Navion	U-18	O-470	AF
NEACP	E-4	CF6-50E	AF
Neptune	P-2	R-3350 & J34	Navy
Nightingale	C-9	JT8D	AF
Orion	P-3	T56	Navy
Osage	TH-55A	H10	Army
Otter	U-1	R-1340	AF/Navy
Peacemaker	AU-23A	TPE331	AF
Phantom II	F-4	J-79	Navy/AF
Provider	C-123	R-2800	AF
Prowler	EA-6B	J-52	Navy
Raven	H-23	O-335/435/540	Army
Sabre	F-86	J47/73	AF
Sabreliner	T-39	J60	AF/Navy
Samaritan	C-131	R-2800/501-D13H	AF
Seabat	SH-34	R-1820	Navy
Seacobra	AH-1J/T	T400	USMC
Seahorse	H-34	R-1820	Navy
Sea King	H-3	T58	Navy
Sea Knight	H-46	T58	Navy
Searanger	TH-57	250-C18	Navy
Seasprite	H-2	T58	Navy
Seastallion	CH-53	T64	Navy
Sea Star	T-1	J33	Navy
Seminole	U-8	O-480	Army
Seneca	H-41A	FSO	Army
Shawnee	H-21	R-1820	Army
Shooting Star	F-80/T-33	J33	AF/Navy
Sioux	H-13	O-335/435	Army
Skyhawk	A-4	J52/65	Navy
Sky Knight	F-10	J34	Navy
Skymaster	C-54	R-2000	AF/Navy
Skyraider	A-1	R-3350	AF/Navy
Skytrain I	C-47/C-117	R-1820/2000	AF/Navy, NG
Skytrain II	C-9B	JT8D	Navy
Skywarrior	A-3	J57	Navy
Stallion	AU-24A	PT6A	AF
Starfighter	F-104	J79	AF
Starlifter	C-141	TF33	AF
Stratocruiser	C-97	R-4360	AF
Stratofortress	B-52	TF33/J57	AF
Stratofreighter	KC-97	R-4360 & J47	AF
Stratojet	B-47	J47	AF
Stratolifter	C-135	TF33/J57	AF
Stratoliner	VC-137	JT3D	AF
Stratotanker	KC-135	J57	AF
Super Constellation	C-121	R-3350	AF
Superfortress	B-29/B-50	R-4360	AF
Super Jolly	HH-53B/C	T64	AF
Super Sabre	F-100	J57	AF
Talon	T-38	J85	AF
Tarhe	CH-54A	JFTD	Army
T-Bird	T-33A	J33	AF
Thunderchief	F-105	J57/75	AF
Thunderflash	RF-84F/K	J65	AF
Thunderstreak	F84F	J65	AF
Tiger I	F-11	J65	Navy
Tiger II	F-5E	J85	AF

TABLE 4-2. CONCLUDED

Popular Names	Model Designation	Basic Engine	Cognizant Service
Tomcat	F-14	TF30/F401	Navy
Tornado	B-45	J47	AF
Tracer	E-1	R-1820	Navy
Tracker	S-2	R-1820	Navy
Trader	C-1	R-1820	Navy
Trojan	T-28	R-1820	Navy/AF
Turbo Mentor	T-34C	PT6A	Navy
Tweet	T-37	J69	AF
Ute	U-21	PT6A	Army
UTTAS	UH-60A	T700	Army
U2	U-2/WU-2	J75	AF/NASA
Vigilante	A-5	J79	Navy
Viking	S-3A	TF34	Navy
Voodoo	F-101	J57	AF
Warning Star	C-121	R-3350	Navy
Workhorse	H-21	R-1820	AF

Similarly, there is a standard military engine nomenclature (Ref. 21). All engines in each service have been classified into the following categories according to the type of engine as indicated by the type letter symbol:

J	Turbojet
T	Turboprop, Turboshaft
F, TF	Turbofan
R	Radial Piston
O	Opposing Piston

Examples of the jet and reciprocating engine designation systems are shown below:

Jet

TF 30 - P - 412A

Type Letter Symbol — TF
Type Numerals — 30
Manufacturer's Symbol — P
Model Indicator — 412A

Reciprocating

R - 1820 - 80 A

Type Letter Symbol — R
Type Numerals — 1820
Model Number — 80
Suffix — A

Manufacturers are coded as follows:

Symbol	Manufacturer	Example
A	Allison	TF41-A-2
GE	General Electric	J79-GE-10
P, PW	Pratt & Whitney	J57-P-420
W	Curtis-Wright	J65-W-5
F	Ford	J57-F-59W
P/F	Pratt & Whitney/Ford	J57-P/F-59W
W/B	Wright/Buick	J65-W/B-7C
L	Lycoming	T53-L-11
CP	United Aircraft of Canada, Ltd	T400-CP-400
G, GA	Garrett Air Research	T76-G-10
R	Ranger	J44-R-3
RR	Rolls-Royce, Ltd	F402-RR-401
T, CA	Teledyne CAE (Continental)	J69-T-25
WE	WECO/Pratt & Whitney	J34-WE-34
BO	Boeing	T50-BO-4
B	Buick	J65-B-5

4.3 DEFINITIONS AND LIMITATIONS

The USEPA document AP-42 (Ref. 1) defines an emission factor as:

> "an estimate of the rate at which a pollutant is released to the atmosphere as a result of some activity, such as combustion or industrial production, divided by the level of that activity (also expressed in terms of a temporal rate). In other words, the emission factor relates the quantity of pollutants emitted to some indicator (activity level) such as production capacity quantity of fuel burned, or vehicle miles traveled."

In the case of aircraft emissions, the most appropriate indicator of activity level is the complete landing-takeoff cycle. However, other choices appear in the literature (cf. Table 4-3).

All of the numerical data presented in this report were collected from other referenced sources. In most cases, the data had to be processed in order to present it here in two forms; mass of pollutant per engine per unit time (in specified modes), and mass of pollutant per aircraft per complete landing/takeoff cycle. Little uniformity of usage was observed to be practiced in the naming of the various quantities used in processing and reporting of aircraft emission data. To avoid confusion and expedite discussion, we have adopted the definitions in Table 4-3, and as follows:

"LTO cycle," the landing-takeoff cycle, incorporates all of the following flight and ground operational modes (at their times-in-mode, TIMs): descent/approach from approximately 3000 ft above ground level (AGL), and including touchdown, landing run, taxi-in, idle and shut-down, start-up and idle, check-out, taxi-out, takeoff, and climb-out to approximately 3000 ft. AGL. In order to make the volume of data manageable and to facilitate comparisons, all of these operations are conventionally grouped into just five standardized modes: taxi/idle (out), takeoff, climbout, approach, and taxi/idle (in).

"TIM," Time-in-Mode: Typical operating time spent by an aircraft in each major operating mode. For military aircraft, the TIM represents normally observed practice for the subject aircraft when operating in the continental U.S.

Some civil TIMs are specified in regulations promulgated by the USEPA, as the basis for determining compliance with mobile source emission standards (Refs. 18 and 19). The remaining civil TIMs represent experience during periods of heavy activity at large, congested metropolitan U.S. airports.

These definitions of LTO cycle and TIMs require some caveats, for the definitions have important restrictions which limit their application in non-average situations.

The use of 3000 ft AGL is a significant assumption which will be invalid at many airports. It represents an average U.S. inversion height, i.e., an

TABLE 4-3. SYMBOLS AND ACRONYMS

Symbol	This Report	Alternatives Used Elsewhere	Definitions	Typical Units
$1000\ \Delta e/\Delta F$	Mass emission rate	Emission index*	Mass of pollutant per engine per 1000 lb of fuel in specified mode	lb/1000 lb
$\Delta e/\Delta t$	Modal emission rate	Modal emission factor	Mass of pollutant per engine per hr. in specified mode	lb/hr
—	(Not used)	Modal emission factor	Mass of pollutant per engine per mode	lb/mode
—	(Not used)	Engine emission factor	Mass of pollutant per engine per LTO cycle	lb/LTO cycle
E^*	Emission factor per LTO cycle	—	Mass of pollutant per aircraft per LTO cycle	lb/LTO cycle
$\Delta F/\Delta f$	Fuel rate	Fuel flow, $\dot{M}_f$	Rate of consumption of fuel per engine per unit time in specified mode	lb/hr
LTO	Landing-takeoff	—	(cf. text)	—
TIM	Time-in-mode	—	(cf. text)	—
AGL	Above ground level	—	(As distinct from elevation or altitude, which can be ambiguous.)	—

*$\Delta e/\Delta F$ corresponds to an emission factor in fuel units, as used in the National Emissions Data System (NEDS), and E corresponds to an emission factor in process units.

average mixing depth for pollutants emitted during the LTO cycle. In an area where the inversion height is actually lower than 3000 ft AFL, relevant NO_x emissions can be significantly overstated and, conversely, the impact of CO and HC emissions might be understated (Ref. 36). This is because the portions of the climbout and approach modes actually spent beneath the inversion layer are the only portions which should contribute to the climbout and approach TIM's in the emission factor calculations.

Meteorologic data are available for many major military and civilian airports. They should be used by any reader, interested in more detail and greater accuracy, to determine site-specific inversion heights. From the inversion height and from aircraft operations data, site-specific climbout and approach TIM's can be developed.

In airfields located in vicinities with a history of low stagnant inversions and air pollution episodes, it may be necessary to perform these calculations for several inversion heights characteristic of various seasons and times of day.

For military aircraft, times in mode will vary greatly between different aircraft type and mission. The variations usually occur for the idle mode because of different arming, queueing, startup, shutdown and taxi operational procedures. For example, the RF-4 (reconnaissance) does not require the F-4E (fighter) arming idle mode time. Special operational procedures can increase the standard LTO idle time by a factor of three. The result is higher carbon monoxide and hydrocarbon emissions (Ref. 38).

The assumption that an LTO cycle necessarily includes the five specified modes will not be correct at military aviation training bases, where a large fraction of all LTO's will be "touch and go" practice. Such operations involve no taxi/idle (in) or taxi/idle (out) modes. The maximum altitude reached may be only 500 to 1000 ft AGL for fixed wing aircraft and very much less for helicopter practice (Refs. 24 and 37). To calculate emissions during touch-and-go practice, the reader will require climbout and approach times appropriate to the training regimen. This information may be obtainable from base operations offices and training commands.

Total air carrier taxi-idle (ground-idle) times of 26 minutes are listed in Table 4-4. These are appropriate for congested metropolitan airports during periods of peak activity. These times will often be very much too high for airports at smaller cities and even for some at larger cities. When possible, the user should employ <u>observed</u> ground idle times.

In summary: TIM data reported herein should be used for guidance only in the absence of specific observations. The military data are not appropriate for primary training. The civil data refer to large, congested fields at times of heavy activity. All the data assume a 3000 ft AGL inversion height.

4.4 CALCULATIONS

If source data are expressed as exhaust concentrations, they can be converted to mass or modal emission rates only if gas volume, temperature, CO_2 concentration, etc., are known. Such calculations are described in detail in the U.S. Navy publication Aircraft Engine Emissions Catalog (Ref. 21). However, most of the source data for this report were modal emission rates (Table 4-3). These were converted to emission factors per LTO cycle by the following algorithm:

1. Locate the engine data in Table 5-2 and select for each of the five standard modes the appropriate power setting (e.g., "after-burner" for takeoff).
2. Using known service assignment and mission, select the appropriate TIM code (column) in Table 4-5.
3. For each mode, m, and pollutant, p, combine data of Tables 4-5 and 5-2:

$$\left(\frac{\Delta e}{\Delta t}\right)_{m,p} \cdot (TIM)_m \quad \text{lb/engine/mode}$$

4. Sum over all modes for each pollutant to produce

$$\sum_m (\Delta e/\Delta t)_{m,p} \cdot (TIM)_m \quad \text{lb/engine/LTO cycle}$$

5. Finally, calculate the emission factor per aircraft per LTO cycle by multiplying by the number of engines, N:

$$E_p = N \sum_m (\Delta e/\Delta t)_{m,p} \cdot (TIM)_m \quad \text{lb/LTO cycle for the aircraft}$$

This kind of calculation can be set up easily on a standard work sheet. With the aid of a hand calculator with one storage location, a conveniently designed work sheet permits the calculations for one aircraft to be completed in about five minutes (Fig. 4-1).

4.5 TIMES IN MODE AND ENGINE POWER SETTINGS

To perform the calculations outlined in Section 4.4, appropriate times in mode must be selected for the aircraft. In the absence of information specific to operation of a particular aircraft at a particular airfield, typical or average times in mode for sometimes broad categories of aircraft are used. Tables 4-4 and 4-5 present the TIM values used in this report.

The military data are in part averages extracted from a report by Naugle and Nelson (Ref. 32), who observed LTOs and interviewed pilots at

Aircraft ____________________ Engines: No. ____ Type ____ Model ____________

Service Using: ____________ Service Data Used ____________ References ____________

TIM Code

Does this check data from another source? Ref. ____________

MODE Mode Code	Power	TIM (min)	Emissions Per Engine									
			CO		NO_x		THC		SO_x		Particulate	
			lb/hr	lb	lb/hr	lb	lb/hr	lb	lb/hr	lb	lb/hr	lb
Taxi/Idle (Out)												
Takeoff												
Climbout												
Approach												
Taxi/Idle (In)												
Total for One Engine				lb		lb		lb		lb		lb
Total for Aircraft				lb		lb		lb		lb		lb
(Emission Factor per LTO Cycle)				kg		kg		kg		kg		kg

Comments:

Figure 4-1. Sample work sheet for calculation of emission factor per LTO cycle.

TABLE 4-4. TYPICAL TIMES-IN-MODE FOR CIVIL LANDING-TAKEOFF CYCLES AT A LARGE CONJESTED METROPOLITAN AIRPORT (REFS. 2, 18, 19)

	Time-In-Mode (Minutes)								
	Air Carrier				General Aviation				Helicopter
Mode	Jumbo Jet[a]	Long Range Jet[a]	Medium Range Jet[a]	Turboprop[b]	Piston Transport	Business Jet	Turboprop[b]	Piston[c]	
Taxi/Idle (Out)	19.0	19.0	19.0	19.0	6.5	6.5	19.0	12.0	3.5
Takeoff	0.7	0.7	0.7	0.5	0.6	0.4	0.5	0.3	—
Climbout	2.2	2.2	2.2	2.5	5.0	0.5	2.5	4.98	6.5
Approach	4.0	4.0	4.0	4.5	4.6	1.6	4.5	6.0	6.5
Taxi/Idle (In)	7.0	7.0	7.0	7.0	6.5	6.5	7.0	4.0	3.5
Total	32.9	32.9	32.9	33.5	23.2	15.5	33.5	27.28	20.0

[a]Same times as EPA classes T2, T3, T4. See footnote a, Table 4-6.
[b]Same times as EPA classes T1 and P2. See footnote a, Table 4-6.
[c]Same times as EPA class P1. See footnote a, Table 4-6.

TABLE 4-5. TIMES-IN-MODE DURING MILITARY CYCLES (REFS. 21, 32).

Mode	Time-in-Mode (Minutes)									
	Combat[a]		Turbine Trainers			Turbine Transport[b]		KC-135 & B-52	Military Piston (All)	Military Helicopter (All)
	USAF	USN	USAF T37 & T38	USAF Other	USN	USAF	USN[c]			
Code	1	2	3	4	2	5	6	7	8	9
Taxi/Idle (Out)	18.5	6.5	12.8	6.8	Same as Code 2	9.2	19.0	32.8	6.5	8.0
Takeoff	0.4	0.4	0.4	0.5		0.4	0.5	0.7	0.6	—
Climbout	0.8	0.5	0.9	1.4		1.2	2.5	1.6	5.0	6.8
Approach	3.5	1.6	3.8	4.0		5.1	4.5	5.2	4.6	6.8
Taxi/Idle (In)	11.3	6.5	6.4	4.4		6.7	7.0	14.9	6.5	7.0
Total	34.5	15.5	24.3	17.1		22.6	33.5	55.2	23.2	28.6

[a]Includes fighters and attack aircraft only.

[b]Includes transport, cargo, observation, patrol, antisubmarine, early warning, and utility; i.e., all turbine aircraft not specifically listed in other columns.

[c]Same time as EPA civil class P2. Cf. footnote, Table 4-6.

five airfields (Nellis, Kelly, Randolph, Wright-Patterson, and Travis) to determine TIMs for nine modes for each major USAF aircraft type. Long idle times for two trainers presumably reflect the complexity of the training regimen, rather than operating characteristics of the engines. Long ground times for the KC-135 and B-52 were said to originate in long check outs for electronic instrumentation.

Modal emission rate data for civil aircraft engines (Table 5-1) are reported conveniently for idle, takeoff climbout, and approach. Both taxi/idle (in) and taxi/idle (out) modes would require "idle" data.

However, varying military mission operating requirements and lack of standards for reporting format have caused military engine modal emission rates for some individual engines to be reported at as many as fourteen power settings. USAF and Navy nomenclature and practices differ. These facts have combined to make the selection of power settings for which to report emissions herein rather less systematic and more cumbersome than for civil aircraft.

As a guide to current practice, Tables 4-6 and 4-7 present standard power settings. Table 4-6 is for information only, as it was not needed to select civil data in this report. Table 4-7, however, was essential, and can be used by the reader who wishes to recalculate table entries for another selection of engine data.

4.6 SUPERSONIC TRANSPORT (SST) AIRCRAFT

The BAC/Aerospatiale Concorde is the only "SST" now in service. In the U.S., it lands only at Dulles, Kennedy, and Dallas-Ft. Worth. Nevertheless, its emission characteristics have elicited sufficient public comment to justify its inclusion in this report.

The Concorde has a 6-mode LTO cycle rather than the 5-mode cycle used for all other fixed wing aircraft reported herein. Its TIM and engine power settings are given in Tables 4-8 and 4-9.

TABLE 4-6. ENGINE POWER SETTINGS FOR THE STANDARD EPA LTO CYCLE FOR COMMERCIAL ENGINES (REF. 21)

Mode	Power Setting (percent thrust or horsepower)			
	Class T1, P2[a]	Class T2, T3, T4[a]	Class P1[a]	Helicopter
Taxi/Idle (out)	Idle	Idle	Idle	
Takeoff	100%	100%	100%	
Climbout	90%	85%	75%-100%	Undefined
Approach	30%	30%	40%	
Taxi/Idle (in)	Idle	Idle	Idle	

[a]As defined by EPA (Refs. 18. 19).

"Class T1" means all aircraft turbofan or turbojet engines except engines of Class T5 of rated power less than 8,000 pounds thrust.

"Class T2" means all turbofan or turbojet aircraft engines except engines of Class T3, T4, and T5 of rated power of 8,000 pounds thrust or greater.

"Class T3" means all aircraft gas turbine engines of the JT3D model family.

"Class T4" means all aircraft gas turbine engines of the JT8D model family.

"Class P1" means all aircraft piston engines, except radial engines.

"Class P2" means all aircraft turboprop engines.

TABLE 4-7. ENGINE POWER SETTINGS FOR A TYPICAL MILITARY CYCLE (REF. 21)

Mode	Power Setting (percent thrust or horsepower)			
	Military Transport	Military Jet	Military Piston	Military Helicopter
Taxi/Idle (out)	Idle	Idle	5-10%	Idle
Takeoff	Military	Military or Afterburner	100%	—
Climbout	90-100%	Military	75%	60-75%
Approach	30%	84-86%	30%	45-50%
Taxi/Idle (in)	Idle	Idle	5-10%	Idle

TABLE 4-8. TIMES-IN-MODE FOR CIVIL SUPERSONIC TRANSPORTS (SSTs) (REF. 20)

Mode	SST Time-In-Mode (min.)[a]
Taxi/Idle (Out)	19.0
Takeoff	1.2
Climbout	2.0
Descent	1.2
Approach	2.3
Taxi/Idle (In)	7.0

[a]Same times as EPA class T5; see footnote, Table 4-9.

TABLE 4-9. ENGINE POWER SETTINGS FOR CIVIL SUPERSONIC TRANSPORTS (SSTs) (REF. 20)

Mode	SST Engine Power (EPA Class T5)[a]
Taxi/Idle (Out)	Idle
Takeoff	100%
Climbout	65%
Descent	15%
Approach	34%
Taxi/Idle (In)	Idle

[a]"Class T5" means all aircraft gas turbine engines employed for propulsion of aircraft designed to operate at supersonic flight speeds.

5. MODAL EMISSION RATES

5.1 CIVIL DATA

The numerical civil data reported in Table 5-1 are reported by USEPA Office of Mobile Source Air Pollution Control (Ref. 2) except for format changes and the addition of SO_x data and particulates data. SO_x emissions are worst case values calculated by material balance, as explained in footnote d. The particulates data are quite old.

5.2 MILITARY DATA

Military data were collected from a variety of sources (references appear in Table 5-2), and in many instances had to be processed for presentation here. Frequently the data were expressed as mass emission rates, $1000\ \Delta e/\Delta F$, ("emission indices"), which are related to modal emission rates, $\Delta e/\Delta t$, as follows:

$$\frac{\Delta e}{\Delta t} = 10^{-3}\ \frac{\Delta F}{\Delta t}\left(1000\ \frac{\Delta e}{\Delta F}\right)$$

where $\Delta F/\Delta t$ is the fuel rate, and all quantities refer to a specified mode, at specified engine power setting.

Sulfur oxides were calculated by material balance, the method being explained in footnote c of Table 5-2.

As for the civil compilation, particulates data are scarce, and some are old. Occasionally SAE smoke numbers were reported, and sometimes % opacity. One researcher used Ringelmann numbers. None of these are currently suitable for conversion to mass quantities usable in this report. As for gaseous pollutants, concentrations cannot be converted to mass/unit time without supporting information such as volumes, temperature, pressure, CO_2 concentration, etc.

Quantitative information related to the accuracy of these data is not often available. However, the U.S. Navy compilation (Ref. 21) includes numerous examples of replicate experiments which permit <u>precision</u> to be estimated. Although beyond the scope of the present work, an analysis of the Navy replicate data would be a useful exercise. Generally, agreeement within $\pm 10\%$ (often very much better) is reported. This is remarkable, since aircraft engine emissions measurements must be among the most difficult source tests performed.

TABLE 5-1. MODAL EMISSION RATES – CIVIL AIRCRAFT ENGINES (REFS. 2, 20)

Model-Series Mfg.[a] Type[a]	Mode	Fuel Rate lb/hr	Fuel Rate kg/hr	CO lb/hr	CO kg/hr	NO_x[b] lb/hr	NO_x[b] kg/hr	Total HC[c] lb/hr	Total HC[c] kg/hr	SO_x[d] lb/hr	SO_x[d] kg/hr	Solid Particulates[e] lb/hr	Solid Particulates[e] kg/hr
250B17B	Idle	63	28.58	6.13	2.76	0.09	0.041	1.27	0.576	0.06	0.03		
All. TP	Takeoff	265	120.2	2.07	0.939	1.75	0.794	0.07	0.032	0.27	0.12		
	Climbout	245	111.1	2.21	1.00	1.46	0.662	0.09	0.041	0.25	0.11		
	Approach	85	38.56	4.13	1.87	0.19	0.086	0.44	0.200	0.09	0.04		
501D22A	Idle	610	276.7	26.60	12.07	2.15	0.975	10.74	4.87	0.61	0.28		
All. TP	Takeoff	2376	1078	4.85	2.20	21.10	9.57	0.67	0.304	2.38	1.08		
	Climbout	2198	997	4.53	2.05	20.27	9.19	1.96	0.889	2.20	1.00		
	Approach	1140	517.1	5.81	2.64	8.54	3.87	2.23	1.01	1.14	0.52		
TPE 331-3	Idle	112.0	50.8	6.89	3.12	0.320	0.145	8.86	4.02	0.11	0.05	0.3[f]	0.14[f]
GA TP	Takeoff	458.0	207.7	0.350	0.159	5.66	2.57	0.050	0.023	0.46	0.21	0.8	0.36
	Climbout	409.0	185.5	0.400	0.181	4.85	2.20	0.060	0.027	0.41	0.19	0.6	0.27
	Approach	250.0	113.4	1.74	0.789	2.48	1.12	0.160	0.073	0.25	0.11	0.6	0.27
TPE331-2	Idle	105.0	47.6	6.73	3.05	0.27	0.22	9.58	4.34	0.11	0.05	(Assume 331-3 data)	
GA TP	Takeoff	405.0	183.7	0.38	0.172	4.14	1.88	0.16	0.072	0.41	0.18		
	Climbout	372.0	168.7	0.51	0.231	3.69	1.67	0.15	0.068	0.37	0.17		
	Approach	220.0	99.8	3.65	1.66	1.82	0.826	0.59	0.268	0.22	0.10		
TPE 731-2	Idle	181.0	82.1	11.11	5.04	0.54	0.245	4.05	1.84	0.18	0.08		
GA TF	Takeoff	1552.0	704.0	1.86	0.844	29.8	13.52	0.14	0.064	1.55	0.70		
	Climbout	1385.0	628.2	1.80	0.816	23.68	10.74	0.12	0.054	1.39	0.63		
	Approach	521.0	236.3	9.53	4.32	3.59	1.63	1.51	0.685	0.52	0.24		
CJ 610-2C	Idle	510.0	231.3	79.05	35.86	0.46	0.209	9.18	4.16	0.51	0.23		
GE TJ	Takeoff	2780.0	1261.0	75.06	34.05	11.68	5.30	0.28	0.127	2.78	1.26		
	Climbout	2430.0	1102.0	65.61	29.76	8.99	4.08	0.49	0.222	2.43	1.10		
	Approach	1025.0	464.9	90.20	40.91	1.54	0.698	2.77	1.26	1.03	0.46		
CF700-2D	Idle	460	208.7	71.30	32.34	0.41	0.186	8.28	3.76	0.46	0.21		
GE TF	Takeoff	2607	1182	57.35	26.01	14.60	6.62	0.26	0.118	2.61	1.18		
	Climbout	2322	1053	58.05	26.33	9.98	4.53	0.23	0.104	2.32	1.05		
	Approach	919	416.9	56.98	25.85	1.65	0.748	1.29	0.585	0.92	0.42		
CF6-6D	Idle	1063	482.2	65.06	29.51	4.88	2.21	21.79	9.88	1.06	0.48	0.04[f]	0.02[f]
GE TF	Takeoff	13750	6237	8.25	3.74	467.5	212.1	8.25	3.74	13.75	6.24	0.54	0.24
	Climbout	11329	5139	6.80	3.03	309.2	140.2	6.80	3.08	11.33	5.14	0.54	0.24
	Approach	3864	1753	23.18	10.51	41.54	18.84	6.96	3.16	3.86	1.75	0.44	0.20
CF6-50C	Idle	1206	547	88.04	39.93	3.02	1.37	36.18	16.41	1.21	0.55	(Assume CF6-6D data)	
GE TF	Takeoff	18900	8573	0.38	0.172	670.95	304.3	0.19	0.086	18.90	8.57		
	Climbout	15622	7104	4.70	2.13	462.0	209.6	0.16	0.073	15.62	7.10		
	Approach	5280	2395	22.70	10.30	52.8	23.95	0.05	0.023	5.28	2.40		

TABLE 5-1 (CONTINUED)

Model-Series Mfg.[a] Type[a]	Mode	Fuel Rate lb/hr	Fuel Rate kg/hr	CO lb/hr	CO kg/hr	NO_x[b] lb/hr	NO_x[b] kg/hr	Total HC[c] lb/hr	Total HC[c] kg/hr	SO_x[d] lb/hr	SO_x[d] kg/hr	Solid Particulates[e] lb/hr	Solid Particulates[e] kg/hr
JT3D-7	Idle	1013	459.5	140.8	63.87	2.23	1.01	124.6	56.52	1.01	0.46	0.45[f]	0.20[f]
P&W TF	Takeoff	9956	4516	8.96	4.06	126.4	57.34	4.98	2.26	9.96	4.52	8.25	3.7
	Climbout	8188	3714	15.56	7.06	78.6	35.65	3.28	1.49	8.19	3.71	8.5	3.9
	Approach	3084	1399	60.14	27.28	16.35	7.42	6.48	2.94	3.08	1.40	8.0	3.6
JT8D-17	Idle	1150	521.6	39.10	17.74	3.91	1.77	10.10	4.58	1.15	0.52	0.36[f,g]	0.16[f,g]
P&W TF	Takeoff	9980	4527	6.99	3.17	202.6	91.90	.50	0.227	9.98	4.53	3.7	1.7
	Climbout	7910	3588	7.91	3.59	123.4	55.97	.40	0.181	7.91	3.59	2.6	1.2
	Approach	2810	1275	20.23	9.18	19.39	8.80	1.41	0.640	2.81	1.28	1.5	0.68
JT9D-7	Idle	1849	838.7	142.4	64.59	5.73	2.60	55.10	24.99	1.85	0.84	2.2[f]	1.0
P&W TF	Takeoff	16142	7322	3.23	1.47	474.6	215.3	0.81	0.367	16.14	7.32	3.75	1.7
	Climbout	13193	5984	6.60	2.99	282.3	128.0	1.32	0.599	13.19	5.98	4.0	1.8
	Approach	4648	2108	44.62	20.24	36.25	16.44	4.65	2.11	4.65	2.11	2.3	1.0
JT9D-70	Idle	1800	816.5	61.20	27.76	5.76	2.61	12.24	0.55	1.80	0.82		
P&W TF	Takeoff	19380	8791	3.88	1.76	600.8	272.5	2.91	1.32	19.38	8.79		
	Climbout	15980	7248	4.79	2.17	386.7	175.4	2.40	1.09	15.98	7.25	(assume JT9D-7 data)	
	Approach	5850	2654	7.61	3.45	47.39	21.50	2.63	1.19	5.85	2.65		
JT15D-1	Idle	215	97.52	19.46	8.83	0.54	0.245	7.48	3.39	0.22	0.10		
PWC TF	Takeoff	1405	637.3	1.41	0.640	14.19	6.44	0	0	1.41	0.64		
	Climbout	1247	565.6	1.25	0.567	11.35	5.15	0	0	1.25	0.57		
	Approach	481	218.2	11.45	5.19	2.45	1.11	1.59	0.721	0.48	0.22		
PT6A-27	Idle	115	52.16	7.36	3.34	0.28	0.127	5.77	2.62	0.12	0.05		
PWC TP	Takeoff	425	192.8	0.43	0.195	3.32	1.51	0	0	0.43	0.19		
	Climbout	400	181.4	0.48	0.218	2.80	1.27	0	0	0.40	0.18		
	Approach	215	97.52	4.95	2.24	1.80	0.816	0.47	0.213	0.22	0.10		
PT6A-41	Idle	147	66.63	16.95	7.69	0.29	0.132	14.94	6.78	0.15	0.07		
PWC TP	Takeoff	510	231.3	2.60	1.18	4.07	1.85	0.89	0.404	0.51	0.23		
	Climbout	473	214.6	3.07	1.39	3.58	1.62	0.96	0.435	0.47	0.21		
	Approach	273	123.8	9.50	4.31	1.27	0.576	6.20	2.81	0.27	0.12		
Spey 555-15[h]	Idle	915	415	83.2	37.7	1.6	0.7	86.0	43.5	0.92	0.42		
RR TF	Takeoff	5734	2600	6.5	3.0	109.2	49.5	29.5	13.4	5.73	2.60		
	Climbout	4677	2121	0.0	0.0	68.7	31.2	2.5	1.1	4.68	2.12		
	Approach	1744	791	34.8	15.8	10.2	4.6	14.3	6.5	1.74	0.79		
Spey MK 511f[h]	Idle	946	429.1	104.4	47.36	0.785	0.356	80.03	36.30	0.95	0.43	0.17	0.077
RR TF	Takeoff	7057	3201	16.16	7.33	156.7	71.08	13.97	6.34	7.06	3.20	16.0	7.3
	Climbout	5752	2609	0.0	0.0	116.8	52.98	0.0	0.0	5.75	2.61	10.0	4.5
	Approach	2204	999.7	48.71	22.09	16.00	7.26	20.56	9.33	2.20	1.00	1.5	0.68
M45H-01[h]	Idle	366	166.0	55.63	25.23	0.622	0.282	11.53	5.23	0.37	0.17		
RR (Bristol)	Takeoff	3590	1628	7.18	3.26	32.31	14.66	0.718	0.326	3.59	1.62		
TF	Climbout	3160	1433	9.48	4.30	25.28	11.47	0.632	0.287	3.16	1.43		
	Approach	1067	484.0	53.56	24.29	3.57	1.62	6.61	3.00	1.07	0.48		

TABLE 5-1 (CONTINUED)

Model-Series Mfg.[a] Type[a]	Mode	Fuel Rate lb/hr	Fuel Rate kg/hr	CO lb/hr	CO kg/hr	NO_x[b] lb/hr	NO_x[b] kg/hr	Total HC[c] lb/hr	Total HC[c] kg/hr	SO_x[d] lb/hr	SO_x[d] kg/hr	Solid Particulates[e] lb/hr	Solid Particulates[e] kg/hr
RB-211-22B[h]	Idle	1718	779.3	137.6	64.42	5.31	2.41	100.1	45.36	1.72	0.78		
RR TF	Takeoff	14791	6709	5.62	2.55	504.1	228.7	29.14	13.22	14.79	6.71		
	Climbout	12205	5536	14.89	6.75	301.9	136.9	8.30	3.76	12.21	5.54		
	Approach	4376	1985	93.78	42.54	32.26	14.63	32.16	14.59	4.38	1.99		
RB-211-524[h]	Idle	1769	802.4	35.91	16.29	4.74	2.15	5.43	2.46	1.77	0.80		
RR TF	Takeoff	17849	8096	7.32	3.32	660.4	299.6	1.96	0.889	17.85	8.10		
	Climbout	14688	6662	7.34	3.33	470.0	213.2	2.50	1.13	14.69	6.67		
	Approach	5450	2472	11.72	5.32	62.89	28.53	0.545	0.247	5.45	2.47		
RB-401-06	Idle	330	149.7	10.07	4.57	0.825	0.374	0.924	0.419	0.33	0.15		
RR TF	Takeoff	2400	1089	2.40	1.09	30.0	13.61	0.120	0.054	2.40	1.09		
	Climbout	2130	966.2	2.77	1.26	24.07	10.92	0.107	0.049	2.13	0.97		
	Approach	775	351.5	5.04	2.29	3.88	1.76	0.155	0.070	0.78	0.35		
Dart RDa7	Idle	411	186.4	37.61	17.06	0.292	0.132	25.52	11.58	0.41	0.19		
RR TP	Takeoff	1409	639.1	4.79	2.17	8.51	3.86	8.75	3.97	1.41	0.64		
	Climbout	1248	566.1	4.26	1.93	5.55	2.52	2.15	0.975	1.25	0.57		
	Approach	645	292.6	21.48	9.74	0.568	0.258	0.0	0.0	0.65	0.29		
Tyne[f]	Idle	619	280.8	40.79	18.50	0.477	0.216	6.63	3.01	0.62	0.28		
RR TP	Takeoff	2372	1076	1.21	0.549	27.11	12.30	2.87	1.31	2.37	1.08		
	Climbout	2188	922.5	1.29	0.585	25.23	11.44	2.63	1.19	2.19	0.99		
	Approach	1095	496.7	11.30	5.13	9.00	4.08	2.68	1.22	1.10	0.50		
Olympus 593	Idle	3060	1388	342.7	155.4	9.72	4.41	119.3	54.11	3.06	1.39		
MK610[h, i]	Takeoff	52200	23673	1513.8	686.5	542.9	246.2	151.4	68.7	52.2	23.7		
RR (Bristol)	Climbout	19700	8936	275.8	125.1	169.4	76.84	31.52	14.30	19.70	8.94		
TJ	Descent	5400	2449	426.6	193.5	18.9	8.6	132.3	60.0	5.4	2.4		
	Approach	9821	4455	451.8	204.9	41.25	18.71	93.30	42.32	9.82	4.46		
0-200	Idle	8.24	3.75	5.31	2.42	0.013	0.006	0.239	0.107	0.0	0		
Con. O	Takeoff	45.17	20.53	44.0	20.0	0.220	0.100	0.940	0.427	0.01	0		
	Climbout	45.17	20.53	44.0	20.0	0.220	0.100	0.940	0.427	0.01	0		
	Approach	25.50	11.59	30.29	13.75	0.029	0.013	0.847	0.385	0.01	0		
TSIO-360C	Idle	11.5	5.21	6.81	3.09	0.022	0.009	1.59	0.723	0.0	0.0		
Con. O	Takeoff	133.	60.3	143.9	65.3	0.36	0.16	1.22	0.55	0.03	0.01		
	Climbout	99.5	45.1	95.6	43.4	0.43	0.20	0.95	0.43	0.02	0.01		
	Approach	61.0	27.7	60.7	27.5	0.23	0.10	0.69	0.31	0.01	0.01		
6-285-B	Idle	72.12	10.03	26.23	11.90	0.0334	0.0152	0.773	0.350	0.0	0.0		
(Tiara)	Takeoff	153.0	69.39	152.7	69.3	0.899	0.408	1.78	0.806	0.03	0.01		
Con. O	Climbout	166.0	52.61	110.9	50.3	0.913	0.414	1.39	0.632	0.02	0.01		
	Approach	83.5	37.88	85.39	38.77	0.394	0.179	1.343	0.609	0.02	0.01		

TABLE 5-1 (CONCLUDED)

Model-Series Mfg.[a] Type[a]	Mode	Fuel Rate lb/hr	Fuel Rate kg/hr	CO lb/hr	CO kg/hr	NO_x[b] lb/hr	NO_x[b] kg/hr	Total HC[c] lb/hr	Total HC[c] kg/hr	SO_x[d] lb/hr	SO_x[d] kg/hr	Solid Particulate[e] lb/hr	Solid Particulate[e] kg/hr
O-320	Idle	9.48	4.30	10.21	4.63	0.0049	0.0022	0.350	0.159	0.0	0.0		
Lyc. O	Takeoff	89.1	40.4	96.0	43.5	0.195	0.088	1.05	0.475	0.02	0.01		
	Climbout	66.7	30.3	66.0	29.9	0.265	0.120	0.826	0.375	0.01	0.01		
	Approach	46.5	21.1	56.8	25.8	0.044	0.020	0.895	0.406	0.01	0.0		
IO-320-DIAD	Idle	7.84	3.56	4.86	2.20	0.009	0.0041	0.283	0.128	0.0	0.0		
Lyc. O	Takeoff	91.67	41.57	109.3	49.55	0.167	0.0756	1.047	0.475	0.02	0.01		
	Climbout	61.42	27.85	54.55	24.74	0.344	0.156	0.588	0.267	0.01	0.01		
	Approach	37.67	17.08	35.57	16.13	0.128	0.058	0.460	0.208	0.01	0.0		
IO-360-B	Idle	8.09	3.68	7.26	3.29	0.0094	0.0042	0.398	0.180	0.0	0.0		
Lyc. O	Takeoff	103.0	46.7	123.5	56.0	0.205	0.093	1.03	0.469	0.02	0.01		
	Climbout	71.7	32.5	70.5	32.0	0.329	0.149	0.585	0.265	0.01	0.01		
	Approach	36.6	16.6	25.3	11.5	0.372	0.169	0.355	0.161	0.01	0.0		
TIO-540-J2B2	Idle	25.06	11.36	32.42	14.70	0.0097	0.0044	1.706	0.774	0.01	0.0		
Lyc. O	Takeoff	259.7	117.8	374.5	169.8	0.094	0.043	3.21	1.46	0.05	0.02		
	Climbout	204.5	92.7	300.8	136.4	0.0481	0.0218	3.40	1.54	0.04	0.02		
	Approach	99.4	45.1	125.4	56.9	0.138	0.0623	1.33	0.604	0.02	0.01		

[a] Abbreviations: All — Detroit Diesel Allison Division of General Motors; Con — Teledyne/Continental; GA — Garrett AiResearch; GE — General Electric; Lyc — Avco/Lycoming; P&W — Pratt & Whitney; PWC — Pratt & Whitney Aircraft of Canada; RR — Rolls Royce; TJ — Turbojet; TF — Turbofan ("fanjet"); TP — Turboprop; O — Reciprocating (Piston) Opposed.

[b] Nitrogen oxides reported as NO_2.

[c] Total hydrocarbons. Includes unburned hydrocarbons and organic pyrolysis products.

[d] Sulfur oxides and sulfuric acid reported as SO_2. Calculated from fuel rate and 0.05 wt% sulfur in Jet A and Jet B fuel, or 0.01 wt% sulfur in aviation gasoline. For turbine engines, the conversion is therefore SO_x (lb/hr) = 10^{-3} (fuel rate), and for piston engines, the conversion is SO_x (lb/hr) = 2×10^{-4} (fuel rate).

[e] All particulate data are from Ref. 39.

[f] The indicated reference does not specify series number for this model engine.

[g] "Diluted smokeless" JT 8D. Note: JT8D is a turbofan engine and is not equivalent to the JT8 (Military J52) turbojet engine.

[h] All Rolls Royce data are based upon an arbitrary 7% idle which does not reflect the actual situation. In reality, Rolls Royce engines will idle at 5-6% with correspondingly higher emissions (Ref. 20).

[i] See discussion of SST LTO-cycle, Section 4.6.

TABLE 5-2. MODAL EMISSION RATES – MILITARY AIRCRAFT ENGINES

Turbojet Model-Series (Civil Version) Mfg. Type[g]	Mode	Fuel Rate		CO		NO_x[a]		Total HC[b]		SO_x[c]		Particulates[d,e]	
		lb/hr	kg/hr	lb/hr	kg/hr	lb/hr	kg/hr	lb/hr	kg/hr	lb/hr	kg/hr	lb/hr	kg/hr
J 52-P-6B (JT8) P&W TJ (Ref. 21)	Idle	778	353	95.8	43.5	1.5	0.7	12.5	5.7	0.8	0.4		
	75% (rpm)	1646	747	59.2	26.9	5.9	2.7	6.3	2.9	1.6	0.7		
	85% (rpm)	2894	1313	53.0	24.0	15.2	6.9	2.4	1.1	2.9	1.3		
	90% (rpm)	3991	1810	43.4	19.7	25.9	11.7	0.9	0.4	4.0	1.8		
	Intermed. (MIL)	6985	3168	30.7	13.9	66.0	29.9	0.0	0.0	7.0	3.2		
J57-P-22 (JT3C) P&W TJ (Refs. 21, 32)	Idle	1087	493	64.4	29.2	2.7	1.2	55.8	25.3	1.1	0.5	8.3	3.8
	75% (rpm)	1693	768	39.8	18.1	5.0	2.3	21.0	9.5	1.7	0.8		
	75% (Thrust)	4885	2216	33.1	15.0	34.4	15.6	9.2	4.2	4.9	2.2		
	Normal Rated	6788	3079	22.4	10.2	61.6	27.9	6.6	3.0	6.8	3.1		
	Intermed. (MIL)	8358	3791	14.9	6.8	93.3	42.3	5.4	2.4	8.4	3.8	12.0	5.4
	Afterburner	35851	16262	1156.0	524.4	152.8	69.3	16.7	7.6	35.9	16.3		
J65-W-20 Wr. TJ (Ref. 21)	Idle	1333	605	66.9	30.3	3.7	1.7	5.0	2.3	1.3	0.6		
	75% (rpm)	2346	1064	51.2	23.2	11.3	5.1	3.2	1.5	2.3	1.0		
	85% (rpm)	3260	1479	52.6	23.9	23.7	10.8	0.9	0.4	3.3	1.5		
	90% (rpm)	3951	1629	56.5	25.6	31.5	14.3	0.5	0.2	4.0	1.8		
	Intermed. (MIL)	6421	2913	49.6	22.5	48.5	22.0	0.2	0.1	6.4	2.9		
J69-T-25 Con. TJ (Ref. 32)	Idle	453	205	48.2	21.9	1.5	0.7	3.6	1.6	0.4	0.2		
	Approach (53% Thrust)	1052	477	50.0	22.7	5.5	2.5	0.04	0.02	1.1	0.5		
	Military	1907	865	39.3	17.8	13.2	6.0	0.04	0.02	1.9	0.9		
J75-P-17 P&W TJ (Ref. 32)	Idle	1700	771	129.5	58.7	2.2	1.0	96.7	43.9	1.7	0.8	0.8	0.4
	Normal Cruise, Approach (90% Thrust)	11300	5126	15.8	7.2	134.5	61.0	1.1	0.5	11.3	5.1	1.1	0.5
	Military	13200	5988	7.9	3.6	108.2	49.1	3.0	1.4	13.2	6.0	13.9	6.3
	Afterburner	53700	24358	644.4	282.2	220.2	99.9	6.4	2.9	53.7	24.4		
J79-GE-10 GE TJ (Refs. 21, 32)	Idle	1100	499	48.0	21.8	3.2	1.5	9.8	4.4	1.1	0.5	57.8	26.2
	75% Thrust	6190	2808	45.6	20.7	69.9	31.7	4.1	1.9	6.2	2.8	67.0 (nom)	30.4
	Intermed. (MIL)	9880	4482	52.0	23.6	151.8	68.9	16.0	7.3	9.9	4.5	77.7	35.2
	Afterburner	35390	16053	611.9	277.6	241.3	109.5	17.2	7.8	35.4	16.1	299.7	135.9
J85-GE-5F GE TJ for T38 (Refs. 21, 23 and 26)	Idle	524	238	93.3	42.3	0.7	0.3	15.7	7.1	0.5	0.2		
	75% (rpm)	798	362	62.4	28.3	1.7	0.8	1.8	0.8	0.8	0.4		
	85% (rpm)	1098	498	63.7	28.9	3.0	1.4	1.3	0.6	1.1	0.5		
	90% (rpm)	1198	543	57.6	26.1	3.7	1.7	0.9	0.4	1.2	0.5		
	Intermed. (MIL)	1297	588	55.8	25.3	3.0	1.4	4.5	2.0	1.3	0.6		
	Afterburner (Max. ST)	8470	3842	245.6	111.4	22.0	10.0	6.8	3.1	8.5	3.9		
J85-GE-21 GE TJ for F-5 (Refs. 21, 23)	Idle	400	181	63.6	28.4	0.5	0.2	9.7	4.4	0.4	0.2		
	75% (rpm)	700	318	64.5	29.3	1.4	0.6	8.7	3.9	0.7	0.3		
	85% (rpm)	1200	544	55.4	25.1	3.5	1.6	3.1	1.4	1.2	0.5		
	90% (rpm)	1500	680	54.9	24.9	5.2	2.4	1.6	0.7	1.5	0.7		
	Intermed. (MIL)	3200	1452	69.0	31.3	16.0	7.3	0.8	0.4	3.2	1.5		
	Afterburner (Max) (J85-GE-5F data)	10650	4831	387.7	175.8	59.6	27.0	1.1	0.5	10.7	4.8		

TABLE 5-2 (CONTINUED)

Turbofan Model-Series (Civil Version) Mgf. Type[g]	Mode	Fuel Rate		CO		NO_x^a		Total HC[b]		SO_x^c		Particulates[d,e]	
		lb/hr	kg/hr	lb/hr	kg/hr	lb/hr	kg/hr	lb/hr	kg/hr	lb/hr	kg/hr	lb/hr	kg/hr
TF30-P-6B	Idle	689	313	47.0	21.3	0.9	0.4	12.9	5.9	0.7	0.3		
(JFT 10)	75% (Thrust)	3550	1610	22.4	10.2	23.7	10.8	10.5	4.8	3.6	1.6		
P&W TF	Normal Rated	4700	2132	26.1	11.8	37.9	17.2	6.6	3.0	4.7	2.1		
for A-7	Intermed. (Mil)	6835	3100	21.1	9.6	82.3	37.3	6.9	3.1	6.8	3.1		
(Ref. 21)													
TF30-P-100	Idle	1260	567	60.0	27.2	3.6	1.6	23.8	10.8	1.3	0.6	33.1	15.0
(JFT 10)	Approach,	6650	3016	4.7	2.1	133.0	60.3	0.7	0.3	6.7	3.0	159.6	72.4
P&W TF	Intermed.	7120	3230	5.0	2.3	199.4	90.4	0.7	0.3	7.1	3.2	59.4	26.9
for F-111	Military	42850	19437	1062.7	482.0	191.5	86.0	85.7	38.9	42.9	19.5	229.7	104.2
(Refs. 26, 32)	Afterburner												
TF30-P-412A	Idle	999	453	68.1	30.9	2.4	1.1	38.4	17.4	1.0	0.5	26.5	12.0
(JFT 10A)	75% (rpm)	1448	6554	55.9	25.4	5.3	2.4	14.0	6.4	1.4	0.6	34.8	15.8
P&W TF)	85% (rpm)	2598	1178	39.5	17.9	18.4	8.3	2.9	1.3	2.6	1.2	46.8 (nom.)	21.2
for F-14	90% (rpm)	3597	1632	22.8	10.3	34.6	15.7	0.6	0.3	3.6	1.6	54.0 (nom.)	24.5
(Refs. 21, 32)	Intermed. (Mil)	7394	3354	15.7	7.1	123.2	55.9	0.7	0.3	7.4	3.4	61.7	28.0
	Afterburner	40000	18144	600.0	272.2	270.0	122.5	40.0	18.1	40.0	18.1	693.2	314.4
TF33-P-3/5/7	Idle	846	384	74.9	34.0	1.5	0.7	77.8	35.3	0.8	0.4	4.4	2.0
(JT3D)	Approach	3797	1722	34.2	15.5	27.7	12.6	14.4	6.5	3.8	1.7	53.1	24.1
P&W TF	Intermed.	7323	3322	13.2	6.0	65.9	29.9	2.9	1.3	7.3	3.3	102.5	46.5
(Refs. 26,32,34)	Military	9979	4526	13.0	5.9	109.8	49.8	3.0	1.4	10.0	4.5	79.8	36.2
TF34-GE-400	Idle	457	207	35.0	15.9	0.6	0.3	7.1	3.2	0.5	0.2		
GE TF	75% (rpm)	459	208	11.1	5.0	1.3	0.6	1.1	0.5	0.5	0.2		
(Refs. 21, 32)	Approach	1296	588	19.4	8.8	10.0	4.5	0.8	0.4	1.3	0.6		
	Intermed. (Mil)	3796	1722	9.3	4.2	20.9	9.5	1.6	0.7	3.8	1.7		
TF39-GE-1	Idle	1130	513	75.7	34.3	3.4	1.5	26.0	11.8	1.1	0.5	0.3	0.1
(JT4A)	Approach,	5740	2604	4.0	1.8	160.7	72.9	1.1	0.5	5.7	2.6	8.0[f]	3.6
GE TF	Intermed.												
(Refs. 26, 32)	Military	11410	5176	8.0	3.6	319.5	144.9	2.3	1.0	11.4	5.2	17.1[f]	7.8
TF41-A-2	Idle	1070	485	114.6	52.0	1.4	0.6	70.8	32.1	1.1	0.5		
All. TF	Approach	5314	2410	27.5	12.5	56.6	25.7	12.9	5.9	5.3	2.4		
(Ref. 21)	(62% Thrust)												
	Intermed. (Mil)	9040	4101	14.4	6.5	201.4	91.4	5.3	2.4	9.0	4.1		
F100-PW-100	Idle	1060	481	20.5	9.3	4.2	1.9	2.4	1.1	1.1	0.5	0.1[f]	0.05
(JTF 22)	Approach	3000	1361	9.0	4.1	33.0	15.0	1.8	0.8	3.0	1.4	1.0[f]	0.5
P&W TF	Military	10400	4717	18.7	8.5	457.6	207.6	0.5	0.2	10.4	4.7	8.6[f]	3.9
(Ref. 32)	Afterburner	44200	20049	2435.4	1104.7	729.3	330.8	4.4	2.0	44.2	20.1	0.0[f]	0.0

TABLE 5-2 (CONTINUED)

Turboprop/Shaft Model-Series (Civil Version) Mfg. Type[g]	Mode	Fuel Rate		CO		NO_x[a]		Total HC[b]		SO_x[c]		Particulates[d,e]	
		lb/hr	kg/hr	lb/hr	kg/hr	lb/hr	kg/hr	lb/hr	kg/hr	lb/hr	kg/hr	lb/hr	kg/hr
PT6A-27	Idle	115	52	7.36	3.34	0.28	0.13	5.77	2.62	0.12	0.05		
PWC TP	Takeoff	425	193	0.43	0.20	3.32	1.51	0	0	0.43	0.20		
(Ref. 2)	Climbout	400	181	0.48	0.22	2.80	1.27	0	0	0.40	0.18		
	Approach	215	98	5.0	2.24	1.80	0.82	0.47	0.21	0.22	0.10		
T53-L-11D	Ground Idle	142	64	4.2	1.9	0.2	0.1	9.0	4.1	0.14	0.06		
(LTC1)	Normal Rated	635	288	3.7	1.7	3.8	1.7	0.3	0.1	0.64	0.29		
Lyc TS	Intermed. (Mil)	674	306	1.9	0.9	3.7	1.7	0.1	0.05	0.67	0.30		
(Ref. 21)	Takeoff/Landing	679	308	2.0	0.9	5.0	2.3	0.2	0.1	0.68	0.31		
T55-L-11A	Ground Idle			29.5	13.4	0.8	4.0	4.0	1.8				
(LTC4)	60% (Thrust)			12.9	5.9	9.1	4.1	0.3	0.1				
Lyc TS	Intermed. (Mil)			14.5	6.6	18.6	8.4	0.2	0.1				
(Ref. 21)	Maximum			12.9	5.9	14.5	6.6	0.2	0.1				
T56-A7	Low Speed Idle	548	249	17.5	7.9	2.1	1.0	11.5	5.2	0.5	0.2	1.6	0.7
All TP	Approach	1053	478	3.7	1.7	7.8	3.5	0.5	0.2	1.1	0.5	3.0	1.4
(Refs. 1,2 6, 32)	Intermediate, Climbout	1908	865	4.6	2.1	17.6	8.0	0.9	0.4	0.9	0.9	3.0	1.4
	Military, Takeoff	2079	943	4.4	2.0	19.3	8.8	0.8	0.4	2.1	1.0	3.7	1.7
T58-GE-5	Idle	133	60	22.5	10.2	0.2	0.1	12.9	5.9	0.1	0.05	0.1	0.05
GE TS	Intermed. (Mil)	821	372	5.6	2.5	5.5	2.5	2.7	1.2	0.8	0.4	0.8	0.4
(Ref. 21)	Power Takeoff	886	402	5.0	2.3	6.4	2.9	0.7	0.3	0.9	0.4	0.8	0.4
	Normal Cruise	757	343	5.8	2.6	4.8	2.2	1.2	0.5	0.8	0.4	0.6	0.3
T63-A-5A	Ground Idle	50	23	5.6	2.5	0.1	0.05	2.4	1.1	0.05	0.02		
(Model 250)	60% Thrust	143	65	3.9	1.8	0.6	0.3	0.5	0.2	0.1	0.05		
All TS	75% Thrust	169	77	3.1	1.4	0.7	0.3	0.3	0.1	0.2	0.1		
(Ref. 21)	Intermed. (Mil)	207	94	1.8	0.8	1.1	0.5	0.3	0.1	0.2	0.1		
T64-GE-6B	Idle	337	153	16.4	7.4	1.3	0.6	4.4	2.0	0.3	0.1	0.1	0.05
GE TS	75% (hp)	1039	471	4.9	2.2	9.3	4.2	0.8	0.4	1.0	0.5	0.6	0.3
(Ref. 21)	Normal Rated	1257	570	3.6	1.6	13.1	5.9	0.9	0.4	1.3	0.6	0.9	0.4
	Intermed. (Mil)	1390	630	3.2	1.5	15.5	7.0	0.9	0.4	1.4	0.6	1.1	0.5
T76	Idle	192	87	4.6	2.1	1.4	0.6	1.4	0.6	0.2	0.09		
(TPE 331-1)	Normal-Cruise	347	157	2.1	1.0	3.4	1.5	0.04	0.02	0.3	0.1		
GA TP	Military	387	176	0.9	0.4	4.0	1.8	0.02	0.01	0.4	0.2		
(Ref. 34)													

TABLE 5-2 (CONCLUDED)

Model-Series (Civil Version) Mfg. Type[g]	Mode	Fuel Rate		CO		NO[a]		Total HC[b]		SO_x[c]		Particulates[d,e]	
		lb/hr	kg/hr	lb/hr	kg/hr	lb/hr	kg/hr	lb/hr	kg/hr	lb/hr	kg/hr	lb/hr	kg/hr
TPE 331-2	Idle	105	47.6	6.7	3.1	0.3	0.1	9.6	4.3	0.1	0.05		
GA TP	Takeoff	405	183.7	0.4	0.2	4.1	1.9	0.2	0.07	0.4	0.2		
(Ref. 2)	Climbout	372	168.7	0.5	0.2	3.7	1.7	0.2	0.07	0.4	0.2		
	Approach	220	99.8	3.7	1.7	1.8	0.8	0.6	0.3	0.2	0.1		
T400-CP-400	Ground Idle	136	62	3.8	1.7	0.3	0.1	1.3	0.6	0.1	0.04	0.06	0.03
(PT6T Twin	Flight Idle	141	64	4.1	1.9	0.4	0.2	1.1	0.5	0.1	0.04		
Pak) PWC TS	Cruise Speed	279	127	0.5	0.2	1.3	0.6	0.0	0	0.3	0.1	0.1 (nom)	0.05
(Refs. 21, 23)	Intermed. (Mil)	406	184	0.0	0	2.4	1.1	0.0	0	0.4	0.2	0.1 (nom)	0.05
	Maximum	1069	485	0.0	0	12.3	5.6	0.2	0.1	1.0	0.5	0.3	0.14
IO-360C	Idle	15.2	6.9	12.9	5.9	0.02	0.01	2.2	1.0	0.00	0.0		
Con O	Approach	67.9	30.8	66.0	30.0	0.4	0.2	1.2	0.5	0.01	0.0		
(Ref. 32)	Military	88.7	40.2	91.5	41.5	0.5	0.2	2.0	0.9	0.02	0.01		
O-470C	Idle	15.1	6.8	11.2	5.1	0.02	0.01	2.9	1.3	0.00	0.0		
Con O	Approach	85.6	38.8	59.2	26.9	0.8	0.4	0.8	0.4	0.02	0.01		
(Ref. 32)	Military	131.3	59.6	151.7	68.8	0.1	0.05	0.4	0.2	0.03	0.01		
R-1820-82	Idle	89	40.3	42.2	19.1	0.0	0	13.4	6.1	0.02	0.01		
Wr R	Approach	323	147	124.3	56.3	2.1	1.0	1.8	0.8	0.06	0.03		
(Ref. 21)	Climbout	862	391	375.0	170.1	1.8	0.8	41.8	19.0	0.2	0.09		
	Takeoff	1166	529	620.0	281.2	2.0	0.9	110.4	50.0	0.2	0.09		

[a]Nitrogen oxides reported as NO_2. Some authors assume 88 wt% NO, rest HNO_3 in combustion water (Ref. 33).

[b]Hydrocarbons. Includes unburned hydrocarbons and organic pyrolysis products.

[c]Sulfur oxides and sulfuric acid reported as SO_2. Calculated from fuel rate and 0.05 wt% sulfur in JP-4 or JP-5 fuel, or 0.01 wt% sulfur in aviation gasoline. For turbine engines, the conversion is therefore SO_x (lb/hr) = 10^{-3} (fuel rate), and for piston engines, the conversion is SO_x (lb/hr) = 2×10^{-4} (fuel rate).

[d]Includes all "condensible particulates," and, thus may be much higher than solid particulates alone (Ref. 32).

[e]"Nom." data are assumed for calculational purposes, in the absence of experimental data.

[f]Dry particles only.

[g]For abbreviations, cf. footnote, Table 4-1.

The number of significant figures reported in Tables 5-1, 5-2 and 6-1 and 6-2 does not imply a corresponding precision. Rather, the significant figures are carried to avoid accumulation of rounding errors.

6. EMISSION FACTORS PER LTO CYCLE

6.1 CIVIL DATA

As discussed in Section 4.1, most of the civil aircraft emission factor data were supplied by the USEPA Office of Mobile Source Air Pollution Control, and simply rearranged as noted earlier. The conversion from modal emission rates to emission factors per LTO cycle is described in Section 4.4. The results of this conversion appear in Tables 6-1 and 6-2.

6.2 MILITARY DATA

Military data appear in Table 6-3. As noted previously, for many engines there are multiple power setting options, often many more than were selected to appear in the Modal Emission Rate table. In order to define in Table 6-3 the selection of power settings from Table 5-2, a "modes code" was introduced. This is explained in footnote b. Conversion from data of Table 5-2 to those of Table 6-3 was performed as described earlier in Section 4.4.

The reader should bear in mind the restrictions and assumptions implicit in these tabulations. As discussed in Section 4.3, these include the altitudes for which the TIMs apply, the engine power settings assumed, the fact that military training exercises involve a great many "touch and go" LTO cycles, and because military ground idle times vary greatly, depending on specific missions. The civil aircraft data correspond only to periods of heavy activity at large, congested metropolitan airports. "Tough and go" practice may be important at some civil airports.

In conclusion, one might quote AP-42:

> "The reader must be herein cautioned not to use these emission factors indiscriminately. That is, the factors generally will not permit the calculation of accurate emissions measurements from an individual installation.......... Factors are more valid when applied to a large number of processes, as, for example, when emission inventories are conducted as part of community or nationwide air pollution studies."

TABLE 6-1. CIVIL AIRCRAFT, COMMERCIAL CARRIER – EMISSION FACTORS PER AIRCRAFT PER LANDING-TAKEOFF CYCLE (REF. 2)

Aircraft	Power Plant[a]			CO		NO_x[b]		Total HC[c]		SO_x[d]		Particulates	
	No.	Mfg.	Model-Series	lb	kg	lb	kg	lb	kg	lb	kg	lb	kg
Short, Medium, Long Range and Jumbo Jets													
BAC/Aerospatiale Concorde	4	RR	Olymp 593	847.0	384.0	91.0	41.0	246.0	112.0	14.1	6.4		
BAC 111-400	2	RR	Spey 511	103.36	46.88	15.04	6.82	72.42	32.85	1.70	0.77	1.46	0.66
Boeing 707-320B	4	P&W	JT3D-7	262.64	119.12	25.68	11.64	218.24	99.00	4.28	1.94	4.52	2.05
Boeing 727-200	3	P&W	JT8D-17	55.95	25.38	29.64	13.44	13.44	6.09	3.27	1.48	1.17	0.53
Boeing 737-200	2	P&W	JT8D-17	37.30	16.92	19.76	8.96	8.96	4.06	2.18	0.99	0.78	0.35
Boeing 747-200B	4	P&W	JT9D-7	259.64	117.76	83.24	37.76	96.92	43.96	7.16	3.25	5.20	2.36
Boeing 747-200B	4	P&W	JT9D-70	108.92	49.40	107.48	48.76	22.40	10.16	7.96	3.61	5.20	2.36
Boeing 747-200B	4	RR	RB211-524	66.76	30.28	124.9	56.65	10.00	4.54	7.52	3.41		
Lockheed L1011-200	3	RR	RB211-524	50.07	27.71	93.66	42.48	7.50	3.40	5.64	2.56		
Lockheed L1011-100	3	RR	RB211-22B	199.4	90.44	64.29	29.16	138.4	62.77	4.95	2.24		
McDonnell-Douglas DC8-63	4	P&W	JT3D-7	262.64	119.12	25.68	11.64	218.24	99.00	3.27	1.48	1.17	0.53
McDonnell-Douglas DC9-50	2	P&W	JT8D-17	37.30	16.92	19.76	8.96	8.96	4.06	2.18	0.99	0.78	0.35
McDonnell-Douglas DC10-30	3	GE	CF6-50C	116.88	53.01	49.59	22.17	47.10	21.36	4.98	2.26	0.21	0.10
Air Carrier Turboprops – Commuter, Feeder Line and Freighters													
Beech 99	2	PWC	PT6A-28	7.16	3.25	0.82	0.37	5.08	2.30	0.18	0.08		
GD/Convair 580	2	All	501	24.38	11.06	21.66	9.82	9.82	4.45	0.92	0.42		
DeHavilland Twin Otter	2	PWC	PT6A-27	7.16	3.25	0.82	0.37	5.08	2.30	0.18	0.08		
Fairchild F27 and FH227	2	RR	R.Da.7	36.26	16.45	0.92	0.42	22.42	10.17	0.58	0.26		
Grumman Goose	2	PWC	PT6A-27	7.16	3.25	0.82	0.37	5.08	2.30	0.18	0.08		
Lockheed L188 Electra	4	All	501	48.76	22.12	43.32	19.65	19.64	8.91	1.84	0.83		
Lockheed L100 Hercules	4	All	501	48.76	22.12	43.32	19.65	19.64	8.91	1.84	0.83		
Swearingen Metro-2	2	GA	TPE 331-3	6.26	2.84	1.16	0.53	7.68	3.48	0.16	0.07	0.46	0.21

[a]Abbreviations: All – Detroit Diesel Allison Division of General Motors; Con – Teledyne/Continental; GA – Garrett AiResearch; GE – General Electric; Lyc – Avco/Lycoming; P&W – Pratt & Whitney; PWC – Pratt & Whitney Aircraft of Canada; RR – Rolls Royce.

[b]Nitrogen oxides reported as NO_2.

[c]Total hydrocarbons (Volatile organics, including unburned hydrocarbons and organic pyrolysis products.)

[d]Sulfur oxides and sulfuric acid reported as SO_2.

TABLE 6-2. CIVIL AIRCRAFT, GENERAL AVIATION – EMISSION FACTORS PER AIRCRAFT PER LANDING-TAKEOFF CYCLE (REF. 2).

Aircraft	Power Plant[a]			CO		NO_x[b]		Total HC[c]		SO_x[d]		Particulates	
	No.	Mfg.	Model-Series	lb	kg	lb	kg	lb	kg	lb	kg	lb	kg
Business Jets													
Cessna Citation	2	P&W	JT15D-1	19.50	8.85	2.00	0.91	6.72	3.05	0.40	0.18		
Dassault Falcon 20	2	GE	CF700-2D	76.14	34.54	1.68	0.76	7.40	3.36	0.78	0.35		
Gates Learjet 24D	2	GE	CJ610-6	88.76	40.26	1.58	0.72	8.42	3.82	0.84	0.38		
Gates Learjet 35, 36	2	GE	TPE 731-2	11.26	5.11	3.74	1.58	3.74	1.70	0.92	0.42		
Rockwell International Shoreliner 75A	2	GE	CF 700	76.14	34.54	1.08	0.76	7.40	3.36	0.78	0.35		
Business Turboprops (EPA Class P2)													
Beech B99 Airliner	2	PWC	PT6A-27	7.16	3.25	0.82	0.37	5.08	2.30	0.18	0.08		
DeHavilland Twin Otter	2	PWC	PT6A-27	7.16	3.25	0.82	0.37	5.08	2.30	0.18	0.08		
Shorts Skyvan-3	2	GA	TPE-331-2	6.44	2.92	0.883	0.400	8.40	3.81	0.16	0.07	0.46	0.21
Swearingen Merlin IIIA	2	GA	TPE-331-3	6.28	2.85	1.15	0.522	7.71	3.50	0.16	0.07	0.46	0.21
General Aviation Piston (EPA Class P1)													
Cessna 150	1	Con	0-200	8.32	3.77	0.02	0.01	0.23	0.10	0.0	0.0		
Piper Warrior	1	Lyc	0-320	14.37	6.52	0.02	0.01	0.26	0.12	0.0	0.0		
Cessna Pressurized Skymaster	2	Con	TS10-360C	33.10	15.01	0.13	0.06	1.15	0.52	0.0	0.0		
Piper Navajo Chieftain	2	Lyc	T10-540	96.24	43.65	0.02	0.01	1.76	0.80	0.0	0.0		

[a] Abbreviations: All – Detroit Diesel Allison Division of General Motors; Con – Teledyne/Continental; GA – Garrett AiResearch; GE – General Electric; Lyc – Avco/Lycoming; P&W – Pratt & Whitney; PWC – Pratt & Whitney Aircraft of Canada; RR – Rolls Royce.

[b] Nitrogen oxides reported as NO_2.

[c] Total hydrocarbons (Volatile organics, including unburned hydrocarbons and organic pyrolysis products.)

[d] Sulfur oxides and sulfuric acid reported as SO_2.

TABLE 6-3. MILITARY AIRCRAFT – EMISSION FACTORS PER AIRCRAFT PER LANDING-TAKEOFF CYCLE

Aircraft		Power Plant		Codes		Emissions per LTO Cycle									
						CO		NO_x[c]		Total HC[d]		SO_x[e]		Particulates[f]	
DOD Desig.	Popular Name	No.	Model – Series	TIM[a]	Modes[b]	lb	kg	lb	kg	lb	kg	lb	kg	lb	kg
Fixed Wing – Turbine															
A-4C	Skyhawk	1	J65-W-20	2	1553	16.62	7.54	2.15	0.98	1.10	0.50	0.46	0.21		
A-6	Intruder	2	J52-P-6B	2	1553	45.26	20.53	3.44	1.56	5.52	2.50	1.58	0.72		
A-7A	Corsair 2	1	TF30-P-6B	2	1442	11.10	5.03	2.05	0.93	3.18	1.44	0.35	0.16		
A-E/G	Corsair 2	1	TF41-A-2	2	1332	25.79	11.70	4.83	2.19	15.76	7.15	0.52	0.24		
A-10	---------	2	TF34-GE-400	1	1443	37.38	16.96	2.60	1.18	7.22	3.27	0.80	0.36		
A-37	Dragon Fly	2	J69-T-25	1	1332	55.28	25.08	2.66	1.21	3.58	1.62	0.60	0.27		
B-52G	Stratofortress	8	J57-P-22	7	1553	441.76	200.38	49.28	22.35	371.12	168.34	10.72	4.86	63.44	28.78
B-52H	Stratofortress	8	TF-33-P-3/5/7	7	1432	504.08	228.65	53.04	24.06	505.76	229.41	10.24	4.64	94.08	42.67
F-4	*Phantom 2*	2	J79-GE-10	2	1432	32.24	14.62	10.88	4.94	4.94	2.24	1.46	0.66	33.92	15.39
F-5	Freedom Fighter/Tiger 2	2	J85-GE-21	1	1653	76.64	34.76	2.10	0.95	10.04	4.55	0.76	0.34		
F-8	Crusader	1	J57-P-22	1	1653	41.82	18.97	5.60	2.54	28.44	12.90	1.19	0.54		
F-14	Tomcat	2	TF30-P-412A	2	1653	39.88	18.09	7.62	3.46	17.36	7.87	1.24	0.56	24.24	11.00
F-15A	Eagle	2	F100-PW-100	1	1432	54.40	24.68	29.96	13.58	2.68	1.22	2.32	1.06	0.44	0.20
F-16	---------	1	F100-PW-100	1	1432	27.20	12.34	14.98	6.79	1.34	0.61	1.16	0.53	0.22	0.10
F-100	Super Sabre	1	J57-P-22	1	1653	41.82	18.97	5.61	2.54	28.44	12.90	1.19	0.54		
F-106	Delta Dart	1	J75-P-17	1	1432	69.65	31.59	11.84	5.37	48.17	21.85	2.04	0.93		
F-111	---------	2	TF30-P-100	1	1432	74.44	33.77	26.94	12.22	24.86	11.28	2.82	1.28	56.12	25.46
C-2	Greyhound	2	T56-A-7	6	1432	16.18	7.34	4.80	2.17	10.14	4.60	0.80	0.36	2.18	0.99
C-5A	Galaxy	4	TF39-GE-1	5	1322	82.12	37.25	79.60	36.11	28.08	12.74	3.84	1.74	4.12	1.87
C-9	Nightingale/Skytrain 2	2	JT8D-17	5	Civ. Table	24.60	11.16	13.02	5.91	5.62	2.55	1.56	0.71	0.62	0.28
C-12	Huron	2	PT6A-27	5	1234	4.78	2.16	0.60	0.27	1.12	0.51	0.12	0.05		
C-130	Hercules	4	T56-A-7	6	1432	32.36	14.68	9.60	4.35	20.28	9.20	1.60	0.73	4.36	1.98
KC-135	Stratotanker	4	J57-P-22	7	1552	220.92	100.21	24.64	11.18	185.56	84.17	5.36	2.43	31.36	14.22
C-141	Starlifter	4	TF33-P-3/5/7	5	1432	92.40	41.91	19.20	8.71	87.68	39.77	3.00	1.36	33.00	14.97
T-2	Buckeye	2	J85-GE-5F	2	1653	48.04	21.79	0.84	0.38	7.06	3.20	0.40	0.18		
T-34C	Turbo Mentor	1	PT6A-27	2	1234	1.73	0.78	0.15	0.07	1.27	0.58	0.03	0.01		
T-37	Tweet	2	J69-T-25	3	1332	38.40	17.42	2.22	1.01	2.26	1.03	0.46	0.21		
T-38	Talon	2	J85-GE-5F	3	1653	72.72	32.99	1.22	0.55	10.42	4.73	0.62	0.28		
T-44	---------	2	PT6A-27	2	1234	3.46	1.57	0.30	0.14	2.54	1.15	0.06	0.03		
P-3C	Orion	4	T56-A-7	6	1432	32.36	14.68	9.60	4.35	20.28	9.20	1.60	0.73	4.36	1.98
S-3A	Viking	2	TF34-GE-400	6	1443	34.18	15.50	4.04	1.83	6.44	2.92	1.02	0.46		
E-2	Hawkeye	2	T56-A-7	6	1432	16.18	7.34	4.80	2.17	10.14	4.60	0.80	0.36	2.18	0.99
E-3A	AWACS	4	TF-33-P-3/5/7	5	1432	92.40	41.91	19.20	8.71	87.68	39.77	3.00	1.36	33.00	14.97
U-21	Ute	2	PT6A-27	5	1234	4.78	2.17	0.06	0.03	3.12	1.42	0.12	0.05		
AU-24	Stallion	1	PT6A-27	5	1234	2.39	1.08	0.03	0.01	1.56	0.71	0.06	0.03		

TABLE 6-3 (CONCLUDED)

Aircraft		Power Plant		Codes		Emissions per LTO Cycle									
						CO		NO_x[c]		Total HC[d]		SO_x[e]		Particulates[f]	
DOD Desig.	Popular Name	No.	Model – Series	TIM[a]	Modes[b]	lb	kg	lb	kg	lb	kg	lb	kg	lb	kg
Fixed Wing – Piston															
C-1	Trader	2	R-1820-82	8	1432	112.44	51.00	0.66	0.30	15.24	6.92	0.04	0.02		
T-28	Trojan	1	R-1820-82	8	1432	56.22	25.50	0.33	0.15	7.62	3.46	0.02	0.01		
T-34	Mentor	1	O-470C	8	1332	21.12	9.58	0.07	0.03	0.71	0.32	0	0		
T-41	Mescelero	1	IO-360C	8	1332	16.41	7.44	0.08	0.04	0.76	0.34	0	0		
O-1	Bird Dog	1	O-470C	8	1332	21.12	9.58	0.07	0.03	0.71	0.32	0	0		
O-2	---------	2	IO-360C	8	1332	32.82	14.88	0.16	0.08	1.52	0.68	0	0		
S-2	Tracker	2	R-1820-82	8	1432	112.44	51.00	0.66	0.30	15.24	6.92	0.04	0.02		
Helicopters – Turbine and Piston															
UH-1H	Iroquois/Huey	1	T53-L-11D	9	1-44	1.55	0.70	1.19	0.54	2.53	1.15	0.20	0.09		
UH-1N	Twin Huey	2	T-400-CP-400	9	1-44	1.90	0.86	1.24	0.56	0.64	0.29	0.24	0.11	0.08	0.04
AH-1G	Huey Cobra	1	T53-L-11D	9	1-44	1.55	0.70	1.19	0.54	2.53	1.15	0.20	0.09		
SH-2D/F	Seasprite	2	T58-GE-5	9	1-33	13.54	6.14	3.02	1.37	6.78	3.08	0.44	0.20	0.40	0.18
HH-3	Sea King/Jolly Green Giant	2	T58-GE-5	9	1-33	13.54	6.14	3.02	1.37	6.78	3.08	0.44	0.20	0.40	0.18
OH-6A	Cayuse	1	T63-A-5A	9	1-32	2.19	0.99	0.31	0.14	0.69	0.31	0.05	0.02		
HH-43	Huskie/Mixmaster	1	T53-L-11D	9	1-44	1.55	0.70	1.19	0.54	2.53	1.15	0.20	0.09		
CH-46	Sea Knight	2	T58-GE-5	9	1-33	13.54	6.14	3.02	1.37	6.78	3.08	0.44	0.20	0.40	0.18
CH-47	Chinook	2	T55-L-11A	9	1-32	20.94	9.50	6.68	3.03	2.10	0.95				
HH-52	---------	1	T58-GE-5	9	1-33	6.77	3.07	1.51	0.68	3.39	1.54	0.22	0.10	0.20	0.09
CH-53	Sea Stallion	2	T64-GE-6B	9	1-22	10.44	4.74	4.84	2.20	2.56	1.16	0.60	0.27	0.32	0.15
HH-53	Super Jolly	2	T64-GE-6B	9	1-22	10.44	4.74	4.84	2.20	2.56	1.16	0.60	0.27	0.32	0.15
OH-58	Kiowa	1	T63-A-5A	9	1-32	2.19	0.99	0.31	0.14	0.69	0.31	0.05	0.02		

[a] The TIM code is defined in Table 4-5.

[b] The four digits of the modes code identify the four line items in Table 5-2 used to calculate modal emissions contributions for Taxi/Idle, Takeoff, Climbout and Approach, respectively. For example, for the F4 Phantom with J79-GE-10 engines, the modes code is 1432. This means that in the J79 engine entry of Table 5-2,

Line 1 (Idle data) were selected to calculate the Taxi/Idle contribution.
Line 4 (Afterburner data) were selected to calculate the Takeoff contribution.
Line 3 (Intermediate (MIL) data) were selected to calculate the Climbout contribution.
Line 2 (75% Thrust data) were selected to calculate the Approach contribution.

For helicopters, there is no takeoff mode. This is indicated by a dash.

[c] Nitrogen oxides reported is NO_2.

[d] Total hydrocarbons. Includes unburned hydrocarbons and organic pyrolysis products.

[e] Sulfur oxides and sulfuric acid reported as SO_2.

[f] See footnotes d, e for Table 5-2.

7. AUXILIARY POWER UNITS

Auxiliary power units (APUs) are employed to produce power for aircraft services when the main engines are not running. Usually APUs are off when main engines are running, i.e., taxiing and flying. Because aircraft power requirements are fairly constant (except for air conditioning), APU power level is dependent largely upon the passenger load and upon the weather (Ref. 35).

There is no duty cycle in usual terms. In order to use the data in the accompanying table, the reader will need to acquire local data on the times for which aircraft are parked at ramps or hangers and on auxiliary power.

TABLE 7-1. AUXILIARY POWER UNIT EMISSION RATES (REF. 35[a])

APU Engine	Manufacturer	Size[b]	Aircraft	Fuel Rate		CO^c		NO_x[c]		Total HC[c]	
				lb/hr	kb/hr	lb/hr	kg/hr	lb/hr	kg/hr	lb/hr	kg/hr
TSCP700-4	AiResearch	770	DC10, Airbus A300	523	237	.6252	0.2836	4.655	2.112	.1247	.0566
GTCP660-4	AiResearch	1180	747	1054	478	9.348	4.240	5.745	2.606	.2384	.1081
GTCP85-129	AiResearch	270	737	270	122	2.454	1.113	1.547	0.714	.0567	.0257
GTCP85-98CK	AiResearch	270	727	270	122	2.033	0.922	1.553	0.704	.0540	.0245
GTCP85-98D	AiResearch	270	DC9	297	135	1.641	0.744	1.783	0.809	.0432	.0196
GTCP30	AiResearch	100	Fairchild F27, Lockheed Jetstar	106	48	0.558	0.253	0.393	0.178	.0147	.0067
GTCP36-6	AiResearch	165	Fairchild F28, Grumman GSII	150	68	1.406	0.638	0.865	0.392	.0611	.0277
ST6	P&W Canada	720	L1011	439	199	0.454	0.206	3.982	1.806	.0360	.0163

[a]Ref. 35 quotes the following original sources:

1. "A Review of Aircraft Gas Turbine Low Emission Technology," Hearing record of the USEPA Aircraft Hearing, January 21, 1976, submitted by the Amer. Soc. Mechanical Engineering
2. "Aircraft Emission Control Program – Status Report," 74-311029-1, Garrett Corp., AiResearch Manufacturing Division, December 4, 1974.

[b]Expressed as equivalent shaft horsepower

[c]Emission rates are expressed as mass of pollutant per hour at maximum power (shaft and bleed extraction). There is no duty cycle as such.

8. REFERENCES

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12. Wallenberger, F. C., E. I. DuPont de Nemours & Company, Seminar presented to North Alabama Section, American Chemical Society Seminar, Huntsville, Ala., 6 March 1978.

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Appendix A

COMPOSITION OF ORGANICS IN ENGINE EXHAUSTS – ADDITIONAL DATA

The data presented herein are reproduced verbatim from the report by Trijonis and Arledge (Ref. 6) discussed in Section 3 of this report. tables contain frequent departures from standard nomenclature. The reader should be cautious in applying the chemical constituent fractions and reactivity class fractions to real total "hydrocarbon" modal emission rates. In Ref. 6, the underlying assumptions and calculational basis for arriving at these data are not described. The reader should not conclude that the rather detailed tables imply a corresponding detail in our knowledge of volatile organic composition.

The piston engine data presented in Ref. 6 and reproduced here are derived from data for automotive engines without emission controls. The assumptions are: (a) reciprocating aircraft and automotive engines are fundamentally similar; (b) the fuel is similar; (c) aircraft engines lack emission controls; and (d) piston engine aircraft emissions make very much smaller contributions to photochemical smog than do turbine engines. Therefore, inaccurate data are more tolerable. These assumptions seem reasonable in the absence of hard data. Actual source tests might not be significantly more difficult than source tests on automobiles. We encountered no literature, however, suggesting that such tests had been done.

TABLE A-1. AVERAGE MOLECULAR WEIGHT OF THE ORGANICS EMITTED IN GAS TURBINE ENGINE EXHAUST, COMPLETE LTO CYCLE (REF. 6).

CLASS I		CLASS II		CLASS III		CLASS IV		CLASS V	
C_1-C_3 paraffins	30	Mono-tert-alkyl (C_{10}) benzenes	134	C_{4+}-paraffins (C_9)	128	Prim-& sec-alkyl (C_8) benzenes	106	Aliphatic olefins	112
Acetylene	26	Cyclic ketones		Cycloparaffins		Dialkyl benzenes (C_9)	120	α-methyl styrene	
Benzene	78	Tert-alkyl acetates		Alkyl acetylenes		Branched alkyl ketones		Aliphatic aldehydes	128
Benzaldehyde		2-nitropropane		Styrene		Prim-& sec-alkyl alcohols		Tri-& tetra-alkyl (C_{11}) benzenes	148
Acetone				N-alkyl ketones		Cellosolve acetate		Unsaturated ketones	
Tert-alkyl alcohols				Prim-& sec-alkyl acetates		Partially halogenated olefins		Diacetone alcohol	
Phenyl acetate				N-methyl pyrrolidone				Ethers	
Methyl benzoate				N,N-dimethyl acetamide				Cellosolves	
Ethyl amines									
Dimethyl formamide									
Methanol									
Perhalogenated hydrocarbons									
Partially halogenated paraffins									

AVERAGE MOLECULAR WEIGHT $\boxed{121}$

TABLE A-2. ORGANIC EMISSIONS FROM GAS TURBINE ENGINES, COMPLETE LTO CYCLE* (REF. 6).

MOLE %

CLASS I		CLASS II		CLASS III		CLASS IV		CLASS V	
C_1-C_3 paraffins	7	Mono-tert-alkyl benzenes	4	C_{4+}-paraffins	38	Prim-& sec-alkyl benzenes	8	Aliphatic olefins	19
Acetylene	1	Cyclic ketones		Cycloparaffins		Dialkyl benzenes	8	α-methyl styrene	
Benzene	1	Tert-alkyl acetates		Alkyl acetylenes		Branched alkyl ketones		Aliphatic aldehydes	10
Benzaldehyde		2-nitropropane		Styrene		Prim-& sec-alkyl alcohols		Tri-& tetra-alkyl benzenes	4
Acetone				N-alkyl ketones		Cellosolve acetate		Unsaturated ketones	
Tert-alkyl alcohols				Prim-& sec-alkyl acetates		Partially halogenated olefins		Diacetone alcohol	
Phenyl acetate				N-methyl pyrrolidone				Ethers	
Methyl benzoate				N,N-dimethyl acetamide				Cellosolves	
Ethyl amines									
Dimethyl formamide									
Methanol									
Perhalogenated hydrocarbons									
Partially halogenated paraffins									
TOTAL CLASS I	9	TOTAL CLASS II	4	TOTAL CLASS III	38	TOTAL CLASS IV	16	TOTAL CLASS V	33

*For more detail, cf., Tables A-3, A-4 and A-5.

TABLE A-3. ESTIMATED COMPOSITION OF THE ORGANICS EMITTED IN GAS TURBINE EXHAUST – TAXI-IDLE MODE (Ref. 6)

Mole %

CLASS I		CLASS II		CLASS III		CLASS IV		CLASS V	
C_1-C_3 paraffins	7	Mono-tert-alkyl benzenes	4	C_{4+}-paraffins	22	Prim-& sec-alkyl benzenes	16	Aliphatic olefins	20
Acetylene	1	Cyclic ketones		Cycloparaffins		Dialkyl benzenes	15	α-methyl styrene	
Benzene	1	Tert-alkyl acetates		Alkyl acetylenes		Branched alkyl ketones		Aliphatic aldehydes	10
Benzaldehyde		2-nitropropane		Styrene		Prim-& sec-alkyl alcohols		Tri-& tetra-alkyl benzenes	4
Acetone				N-alkyl ketones		Cellosolve acetate		Unsaturated ketones	
Tert-alkyl alcohols				Prim-& sec-alkyl acetates		Partially halogenated olefins		Diacetone alcohol	
Phenyl acetate				N-methyl pyrrolidone				Ethers	
Methyl benzoate				N,N-dimethyl acetamide				Cellosolves	
Ethyl amines									
Dimethyl formamide									
Methanol									
Perhalogenated hydrocarbons									
Partially halogenated paraffins									
TOTAL CLASS I	9	TOTAL CLASS II	4	TOTAL CLASS III	22	TOTAL CLASS IV	31	TOTAL CLASS V	34

TABLE A-4. ESTIMATED COMPOSITION OF THE ORGANICS EMITTED IN GAS TURBINE EXHAUST – TAKEOFF MODE (Ref. 6)

MOLE %

CLASS I		CLASS II		CLASS III		CLASS IV		CLASS V	
C_1-C_3 paraffins	2	Mono-tert-alkyl benzenes	6	C_{4+}-paraffins	15	Prim-& sec-alkyl benzenes	8	Aliphatic olefins	20
Acetylene		Cyclic ketones		Cycloparaffins		Dialkyl benzenes	13	α-methyl styrene	
Benzene		Tert-alkyl acetates		Alkyl acetylenes		Branched alkyl ketones		Aliphatic aldehydes	30
Benzaldehyde		2-nitropropane		Styrene		Prim-& sec-alkyl alcohols		Tri-& tetra-alkyl benzenes	6
Acetone				N-alkyl ketones		Cellosolve acetate		Unsaturated ketones	
Tert-alkyl alcohols				Prim-& sec-alkyl acetates		Partially halogenated olefins		Diacetone alcohol	
Phenyl acetate				N-methyl pyrrolidone				Ethers	
Methyl benzoate				N,N-dimethyl acetamide				Cellosolves	
Ethyl amines									
Dimethyl formamide									
Methanol									
Perhalogenated hydrocarbons									
Partially halogenated paraffins									
TOTAL CLASS I	2	TOTAL CLASS II	6	TOTAL CLASS III	15	TOTAL CLASS IV	21	TOTAL CLASS V	56

TABLE A-5. ESTIMATED COMPOSITION OF THE ORGANICS EMITTED IN GAS TURBINE EXHAUST — APPROACH MODE (REF. 6).

MOLE %

CLASS I		CLASS II		CLASS III		CLASS IV		CLASS V	
C_1-C_3 paraffins	1	Mono-tert-alkyl benzenes		C_{4+}-paraffins	10	Prim-& sec-alkyl benzenes	9	Aliphatic olefins	10
Acetylene		Cyclic ketones		Cycloparaffins		Dialkyl benzenes	9	α-methyl styrene	
Benzene	1	Tert-alkyl acetates		Alkyl acetylenes		Branched alkyl ketones		Aliphatic aldehydes	60
Benzaldehyde		2-nitropropane		Styrene		Prim-& sec-alkyl alcohols		Tri-& tetra-alkyl benzenes	
Acetone				N-alkyl ketones		Cellosolve acetate		Unsaturated ketones	
Tert-alkyl alcohols				Prim-& sec-alkyl acetates		Partially halogenated olefins		Diacetone alcohol	
Phenyl acetate				N-methyl pyrrolidone				Ethers	
Methyl benzoate				N,N-dimethyl acetamide				Cellosolves	
Ethyl amines									
Dimethyl formamide									
Methanol									
Perhalogenated hydrocarbons									
Partially halogenated paraffins									
TOTAL CLASS I	2	TOTAL CLASS II	0	TOTAL CLASS III	10	TOTAL CLASS IV	18	TOTAL CLASS V	70

TABLE A-6. AVERAGE MOLECULAR WEIGHT OF THE ORGANICS EMITTED IN PISTON ENGINE AIRCRAFT EXHAUST (REF. 6).

CLASS I		CLASS II		CLASS III		CLASS IV		CLASS V	
C_1-C_3 paraffins	20	Mono-tert-alkyl benzenes		C_{4+}-paraffins	97	Prim-& sec-alkyl benzenes	92	Aliphatic olefins	40
Acetylene	26	Cyclic ketones		Cycloparaffins	110	Dialkyl benzenes	113	α-methyl styrene	
Benzene	78	Tert-alkyl acetates		Alkyl acetylenes		Branched alkyl ketones		Aliphatic aldehydes	
Benzaldehyde		2-nitropropane		Styrene		Prim-& sec-alkyl alcohols		Tri-& tetra-alkyl benzenes	123
Acetone				N-alkyl ketones		Cellosolve acetate		Unsaturated ketones	
Tert-alkyl alcohols				Prim-& sec-alkyl acetates		Partially halogenated olefins		Diacetone alcohol	
Phenyl acetate				N-methyl pyrrolidone				Ethers	
Methyl benzoate				N,N-dimethyl acetamide				Cellosolves	
Ethyl amines									
Dimethyl formamide									
Methanol									
Perhalogenated hydrocarbons									
Partially halogenated paraffins									

AVERAGE MOLECULAR WEIGHT **56**

TABLE A-7. COMPOSITION OF THE ORGANICS EMITTED IN PISTON AIRCRAFT ENGINE EXHAUST (AS APPROXIMATED BY UNCONTROLLED AUTOMOTIVE EMISSIONS) (REF. 6).

Mole %

CLASS I		CLASS II		CLASS III		CLASS IV		CLASS V	
C_1-C_3 paraffins	20	Mono-tert-alkyl benzenes		C_{4+}-paraffins	22	Prim-& sec-alkyl benzenes	6	Aliphatic olefins	31
Acetylene	12	Cyclic ketones		Cycloparaffins	1	Dialkyl benzenes	4	α-methyl styrene	
Benzene	2	Tert-alkyl acetates		Alkyl acetylenes		Branched alkyl ketones		Aliphatic aldehydes	
Benzaldehyde		2-nitropropane		Styrene		Prim-& sec-alkyl alcohols		Tri-& tetra-alkyl benzenes	2
Acetone				N-alkyl ketones		Cellosolve acetate		Unsaturated ketones	
Tert-alkyl alcohols				Prim-& sec-alkyl acetates		Partially halogenated olefins		Diacetone alcohol	
Phenyl acetate				N-methyl pyrrolidone				Ethers	
Methyl benzoate				N,N-dimethyl acetamide				Cellosolves	
Ethyl amines									
Dimethyl formamide									
Methanol									
Perhalogenated hydrocarbons									
Partially halogenated paraffins									
TOTAL CLASS I	34	TOTAL CLASS II	0	TOTAL CLASS III	23	TOTAL CLASS IV	10	TOTAL CLASS V	33

Appendix B

SUGGESTED REVISION OF SECTION 3.2.1 "AIRCRAFT" OF AP-42

Material appearing in this appendix represents a condensation of the data and discussion presented in the body of this document. It is intended to be self-contained, since it is proposed for use in AP-42 with changes in page, paragraph, and table numbers only. Consequently, this appendix contains its own references.

B.1 AIRCRAFT

B.1.1 General

Aircraft engines are of two major categories: reciprocating (piston) and gas turbine.

The basic element in the aircraft piston engine is the combustion chamber, or cylinder, in which mixtures of fuel and air are burned and from which energy is extracted through a piston and crank mechanism that drives a propeller. The majority of aircraft piston engines have two or more cylinders and are generally classified according to their cylinder arrangement – either "opposed" or "radial." Opposed engines are installed in most light or utility aircraft; radial engines are used mainly in large transport aircraft. Almost no single-row inline or V-engines are used in current aircraft.

The gas turbine engine in general consists of a compressor, a combustion chamber, and a turbine. Air entering the forward end of the engine is compressed and then heated by burning fuel in the combustion chamber. The major portion of the energy in the heated air stream is used for aircraft propulsion. Part of the energy is expended in driving the turbine, which in turn drives the compressor. Turbofan and turboprop or turboshaft engines use energy from the turbine for propulsion; turbojet engines use only the expanding exhaust stream for propulsion. The terms "propjet" and "fanjet" are sometimes used for turboprop and turbofan, respectively.

The aircraft in the following tables include only those believed to be significant now, or those which will become significant shortly due to procurements over the next few years.

Few piston engine aircraft data appear here. Military fixed wing piston aircraft, even among trainers, are being phased out. One piston engine helicopter, the TH-55A "Osage" sees extensive use at one training base at Ft. Rucker, Ala. (EPA Region IV); however, engine emissions data are not available. Most civil piston engine aircraft are in general aviation service.

The fact that a particular aircraft is not listed in the following tables does not imply that emission factors cannot be calculated. It is the engine emissions and the time-in-mode category which determine emissions. If these are known, emission factors can be calculated in the same way that the following tables were developed.

The aircraft classification system used is listed in Table B.1-1 and B.1-2. Aircraft have been divided into sub-classes depending on the kind of aircraft and the most commonly used engine for that class. Jumbo jets normally have approximately 40,000 lb maximum thrust per engine, and medium-range jets have about 14,000 lb maximum thrust per engine. Small piston engines develop less than 500 horsepower.

B.1.2 The Landing Takeoff Cycle and Times in Mode

A landing take-off cycle (LTO cycle) incorporates all of the normal flight and ground operational modes (at their respective times-in-mode, TIMs), including: descent/approach from approximately 3000 ft (914 m) above ground level (AGL), touchdown, landing run, taxi-in, idle and shut-down, start-up and idle, check out, taxi-out, takeoff, and climbout to 3000 ft (914 m) AGL.

In order to make the available data manageable, and to facilitate comparisons, all of these operations are conventionally grouped into five standardized modes: approach, taxi/idle (in), taxi/idle (out), takeoff and climbout. There are exceptions. The supersonic transport (SST) has a descent mode preceding approach. Helicopters omit the takeoff mode. Training exercises involve "touch and go" practice. These omit the taxi/idle modes, and the maximum altitude reached is much lower. Hence the duration (TIM) of the approach and climbout modes will be shorter.

Each class of aircraft has its own typical LTO cycle (set of TIMs). For major classes of aircraft, these are shown in Tables B.1-3 and B.1-4. The TIM data appearing in those tables should be used for guidance only and in the absence of specific observations. The military data are inappropriate to primary training. The civil data refer to large, congested fields at times of heavy activity.

All of the data assume a 3000 ft AGL inversion height, an average U.S. mixing depth. This may be inappropriate at specific localities and times, for which site-specific and time-specific inversion height data should be sought. Aircraft emissions of concern here are those released to the atmosphere below the inversion. If local conditions suggest higher or lower inversions, the duration (TIM) of the approach and climbout modes must be adjusted correspondingly.

TABLE B.1-1 CIVIL AIRCRAFT CLASSIFICATION[a]

Aircraft	Engines[b]			
	No.	Mfg.	Type	Model-Series
<u>Supersonic Transport</u>				
BAC/Aerospatiale Concorde	4	RP	TJ	Olymp. 593-610
<u>Short, Medium, Long Range and Jumbo Jets</u>				
BAC 111-400	2	RR	TF	Spey 511
Boeing 707-320B	4	P&W	TF	JT3D-7
Boeing 727-200	3	P&W	TF	JT8D-17
Boeing 737-200	2	P&W	TF	JT8D-17
Boeing 747-200B	4	P&W	TF	JT9D-7
Boeing 747-200B	4	P&W	TF	JT9D-70
Boeing 747-200B	4	RR	TF	RB211-524
Lockheed L1011-200	3	RR	TF	RB211-524
Lockheed L1011-100	3	RR	TF	RB211-22B
McDonnell-Douglas DC8-63	4	P&W	TF	JT3D-7
McDonnell-Douglas DC9-50	2	P&W	TF	JT8D-17
McDonnell-Douglas DC10-30	3	GE	TF	CF6-50C
<u>Air Carrier Turboprops – Commuter, Feeder Line and Freighters</u>				
Beech 99	2	PWC	TP	PT6A-28
GD/Convair 580	2	All	TP	501
DeHavilland Twin Otter	2	PWC	TP	PT6A-27
Fairchild F27 and FH227	2	RR	TP	R. Da. 7
Grumman Goose	2	PWC	TP	PT6A-27
Lockheed L188 Electra	4	All	TP	501
Lockheed L100 Hercules	4	All	TP	501
Swearingen Metro-2	2	GA	TP	TPE 331-3
<u>Business Jets</u>				
Cessna Citation	2	P&W	TF	JT15D-1
Dassault Falcon 20	2	GE	TF	CF700-2D
Gates Learjet 24D	2	GE	TJ	CJ610-6
Gates Learjet 35, 36	2	GE	TF	TPE 731-2
Rockwell International Shoreliner 75A	2	GE	TF	CF 700
<u>Business Turboprops (EPA Class P2)</u>				
Beech B99 Airliner	2	PWC	TP	PT6A-27
DeHavilland Twin Otter	2	PWC	TP	PT6A-27
Shorts Skyvan-3	2	GA	TP	TPE-331-2
Swearingen Merlin IIIA	2	GA	TP	TPE-331-3
<u>General Aviation Piston (EPA Class P1)</u>				
Cessna 150	1	Con	O	0-200
Piper Warrior	1	Lyc	O	0-320
Cessna Pressurized Skymaster	2	Con	O	TS10-360C
Piper Navajo Chieftain	2	Lyn	O	T10-540

[a]References 1, 2

[b]Abbreviations: TJ – turbojet; TF – turbofan; TP – turboprop; R – reciprocating piston; O – opposed piston. All – Detroit Diesel Allison Division of General Motors; Con – Teledyne/Continental; GA – Garrett AiResearch; GE – General Electric; Lyc – Avco/Lycoming; P&W – Pratt & Whitney; PWC – Pratt & Whitney Aircraft of Canada; RR – Rolls Royce.

TABLE B.1-2. MILITARY AIRCRAFT CLASSIFICATIONS[a]

Aircraft Mission (Class)	DOD Designation	Popular Name	Manufacturer[b]	Service	Power Plant: No. & Type[c]	Power Plant: Mfg.[b]	Power Plant: Designation
Combat	A-4	Skyhawk	McD-Doug	USN, USMC	1 TJ	P&W	J52, J65
	A-7	Corsair 2	Vought	USN	1 TF	All, P&W	TF41, TF30
	F-4	Phantom 2	McD-Doug	USAF, USN	2 TJ	GE	J79
	F-5	Freedom Fighter (Tiger 2)	Northrop	USAF	2 TJ	GE	J85
	F-14	Tomcat	Grumman	USN	2 TF	P&W	TF30, F401
	F-15A	Eagle	McD-Doug	USAF	2 TF	P&W	F100
	F-16	--------	GD/FW	USAF	1 TF	P&W	F100
Bomber	B-52	Stratofortress	Boeing	USAF	8 TJ, TF	P&W	J57, TF33
Transport Patrol/Antisub	C-5A	Galaxy	GELAC	USAF	4 TF	GE	TF39
	C-130	Hercules	GELAC	USAF, USN, USCG	4 TP	All	T56
	KC-135	Stratotanker	Boeing	USAF	4 TJ	P&W	J57
	C-141	Starlifter	GELAC	USAF	4 TF	P&W	TF33
	P-3C	Orion	CALAC	USN	4 TP	All	T56
	S-3A	Viking	CALAC	USN	2 TF	GE	TF34
Trainer	T-34C	Turbo Mentor	Beech	USN	1 TP	PWC	PT6A
	T-38	Talon	Northrop	USAF	2 TJ	GE	J85
Helicopters	UH-1H	Iroquois ("Huey")	Bell Heli	USA, USN	1 TS	Lyc, GE	T53, T58
	HH-3	Sea King ("Jolly Green Giant")	Sikorsky	USAF, USN, USCG	2 TS	GE	T58
	CH-47	Chinook	Booeing Vertol	USA	2 TS	Lyc	T55

[a]Ref. 1.

[b]Abbreviations: All – Detroit Diesel Allison Division of General Motors; CALAC – Lockheed-California; GD/FW – General Dynamics, Ft. Worth; GE – General Electric; GELAC – Lockheed-Georgia; Lyc – Lycoming; McD-Doug – McDonnell Douglas; P&W – Pratt & Whitney; PWC – Pratt & Whitney Aircraft of Canada.

[c]TJ – Turbojet; TF – Turbofan; TP – Turboprop; TS – Turboshaft.

TABLE B.1-3. TYPICAL TIMES-IN-MODE FOR CIVIL LANDING-TAKEOFF CYCLES AT A LARGE, CONGESTED METROPOLITAN AIRPORT[a]

Mode	Time-In-Mode (Minutes)								
	Air Carrier				General Aviation				Helicopter
	Jumbo Jet[b]	Long Range Jet[b]	Medium Range Jet[b]	Turboprop[c]	Piston Transport	Business Jet	Turboprop[c]	Piston[d]	
Taxi/Idle (Out)	19.0	19.0	19.0	19.0	6.5	6.5	19.0	12.0	3.5
Takeoff	0.7	0.7	0.7	0.5	0.6	0.4	0.5	0.3	—
Climbout	2.2	2.2	2.2	2.5	5.0	0.5	2.5	4.98	6.5
Approach	4.0	4.0	4.0	4.5	4.6	1.6	4.5	6.0	6.5
Taxi/Idle (In)	7.0	7.0	7.0	7.0	6.5	6.5	7.0	4.0	3.5
Total	32.9	32.9	32.9	33.5	23.2	15.5	33.5	27.28	20.0

[a]Ref. 3.

[b]Same times as EPA classes T2, T3, T4. See footnote b, Table B.1-5.

[c]Same times as EPA classes T1 and P2. See footnote b, Table B.1-5.

[d]Same times as EPA class P1. See footnote b, Table B.1-5.

TABLE B.1-4. TIMES-IN-MODE DURING MILITARY CYCLES[a]

Mode	Time-in-Mode (Minutes)									
	Combat[b]		Turbine Trainers			Turbine Transport[c]		KC-135 & B-52	Military Piston (All)	Military Helicopter (All)
	USAF	USN	USAF T-38	USAF Other	USN	USAF	USN[d]			
Code	1	2	3	4	2	5	6	7	8	9
Taxi/Idle (Out)	18.5	6.5	12.8	6.8	6.5	9.2	19.0	32.8	6.5	8.0
Takeoff	0.4	0.4	0.4	0.5	0.4	0.4	0.5	0.7	0.6	—
Climbout	0.8	0.5	0.9	1.4	0.5	1.2	2.5	1.6	5.0	6.8
Approach	3.5	1.6	3.8	4.0	1.6	5.1	4.5	5.2	4.6	6.8
Taxi/Idle (In)	11.3	6.5	6.4	4.4	6.5	6.7	7.0	14.9	6.5	7.0
Total	34.5	15.5	24.3	17.1	15.5	22.6	33.5	55.2	23.2	28.6

[a] Reference 1.

[b] Includes fighters and attack aircraft only.

[c] Includes transport, cargo, observation, patrol, antisubmarine, early warning, and utility; i.e., all turbine aircraft not specifically listed in other columns.

[d] Same as EPA specified class P2 for civil turboprops.

A more detailed discussion of the assumptions and limitations implicit in these data appears in Ref. 1.

Emission factors in Tables B.1-9 and B.1-10 were determined using the times-in-mode presented in Tables B.1-3 and B.1-4, and generally for the engine power settings given in Tables B.1-5 and B.1-6.

B.1-3 Modal Emission Rates and Emission Factors per LTO Cycle

The first step in the calculation of aircraft emission factors is the development of a set of modal emission rates. These represent the quantity of pollutant released per unit time in each of the standard modes. Each mode is characterized by an engine power setting (Tables B.1-5 and B.1-6) and a fuel rate, the quantity of fuel combusted per unit time.

The procedure for calculation of aircraft emission factors per LTO cycle starting with engine modal emission rates, follows:

1. For a specific aircraft, determine the number and model of engines, using for example, Table B.1-1 or B.1-2.
2. Using Table B.1-7 or B.1-8, locate the appropriate engine data, and prepare a list of modal emission rates

$$\left(\frac{\Delta e}{\Delta t}\right)_{m,p}$$

   for each mode m and pollutant p.
3. Using known military assignment and mission or civil aircraft type and application, use Table B.1-3 or B.1-4 to select an appropriate set of times-in-mode $(TIM)_m$.
4. For each mode m and pollutant p, multiply the modal emission rate and TIM data for each mode and sum over all modes. This will yield an emission factor per engine, which must be multiplied by the number of engines, N, to produce the emission factor per LTO cycle, E_p, for an aircraft:

$$E_p = N \sum_m \left(\frac{\Delta e}{\Delta t}\right)_{m,p} \cdot (TIM)_m$$

This calculation can be set up easily on a hand calculator with one storage location, using a conveniently laid out work sheet.

Emission factors calculated in exactly this way are presented in Tables B.1-9 and B.1-10.

TABLE B.1-5. ENGINE POWER SETTINGS FOR THE STANDARD EPA LTO CYCLE FOR COMMERCIAL ENGINES[a]

Mode	Power Setting (percent thrust or horsepower)			
	Class T1, P2[b]	Class T2, T3, T4[b]	Class P1[b]	Helicopter
Taxi/Idle (out)	Idle	Idle	Idle	
Takeoff	100%	100%	100%	
Climbout	90%	85%	75%-100%	Undefined
Approach	30%	30%	40%	
Taxi/Idle (in)	Idle	Idle	Idle	

[a]Refs. 1, 3.

[b]As defined by EPA (Ref. 3).

"Class T1" means all aircraft turbofan or turbojet engines except engines of Class T5 of rated power less than 8,000 pounds thrust.

"Class T2" means all turbofan or turbojet aircraft engines except engines of Class T3, T4, and T5 of rated power of 8,000 pounds thrust or greater.

"Class T3" means all aircraft gas turbine engines of the JT3D model family.

"Class T4" means all aircraft gas turbine engines of the JT8D model family.

"Class T5" means all aircraft gas turbine engines employed for propulsion of aircraft designed to operate at supersonic flight speeds.

"Class P1" means all aircraft piston engines, except radial engines.

"Class P2" means all aircraft turboprop engines.

TABLE B. 1-6. ENGINE POWER SETTINGS FOR A TYPICAL MILITARY CYCLE[a]

Mode	Power Setting (percent thrust or horsepower)			
	Military Transport	Military Jet	Military Piston	Military Helicopter
Taxi/Idle (out)	Idle	Idle	5-10%	Idle
Takeoff	Military	Military or Afterburner	100%	—
Climbout	90-100%	Military	75%	60-75%
Approach	30%	84-86%	30%	45-50%
Taxi/Idle (in)	Idle	Idle	5-10%	Idle

[a]Ref. 1.

TABLE B.1-7. MODAL EMISSION RATES – CIVIL AIRCRAFT ENGINES[a]

Model-Series Mfg.[b] Type[b]	Mode	Fuel Rate lb/hr	Fuel Rate kg/hr	CO lb/hr	CO kg/hr	NO_x[c] lb/hr	NO_x[c] kg/hr	Total HC[d] lb/hr	Total HC[d] kg/hr	SO_x[e] lb/hr	SO_x[e] kg/hr	Solid Particulates[f] lb/hr	Solid Particulates[f] kg/hr
250B17B All. TP	Idle	63	28.58	6.13	2.78	0.09	0.041	1.27	0.576	0.06	0.03		
	Takeoff	265	120.2	2.07	0.939	1.75	0.794	0.07	0.032	0.27	0.12		
	Climbout	245	111.1	2.21	1.00	1.46	0.662	0.09	0.041	0.25	0.11		
	Approach	85	38.56	4.13	1.87	0.19	0.086	0.44	0.200	0.09	0.04		
501D22A All. TP	Idle	610	276.7	26.60	12.07	2.15	0.975	10.74	4.87	0.61	0.28		
	Takeoff	2376	1078	4.85	2.20	21.10	9.57	0.67	0.304	2.38	1.08		
	Climbout	2198	997	4.53	2.05	20.27	9.19	1.96	0.889	2.20	1.00		
	Approach	1140	517.1	5.81	2.64	8.54	3.87	2.23	1.01	1.14	0.52		
TPE 331-3 GA TP	Idle	112.0	50.8	6.89	3.12	0.320	0.145	8.86	4.02	0.11	0.05	0.3[g]	0.14[g]
	Takeoff	458.0	207.7	0.350	0.159	5.66	2.57	0.050	0.023	0.46	0.21	0.8	0.36
	Climbout	409.0	185.5	0.400	0.181	4.85	2.20	0.060	0.027	0.41	0.19	0.6	0.27
	Approach	250.0	113.4	1.74	0.789	2.48	1.12	0.160	0.073	0.25	0.11	0.6	0.27
TPE331-2 GA TP	Idle	105.0	47.6	6.73	3.05	0.27	0.22	9.58	4.34	0.11	0.05	(Assume 331-3 data)	
	Takeoff	405.0	183.7	0.38	0.172	4.14	1.88	0.16	0.072	0.41	0.18		
	Climbout	372.0	168.7	0.51	0.231	3.69	1.67	0.15	0.068	0.37	0.17		
	Approach	220.0	99.8	3.65	1.66	1.82	0.826	0.59	0.268	0.22	0.10		
TPE 731-2 GA TF	Idle	181.0	82.1	11.11	5.04	0.54	0.245	4.05	1.84	0.18	0.08		
	Takeoff	1552.0	704.0	1.86	0.844	29.8	13.52	0.14	0.064	1.55	0.70		
	Climbout	1385.0	628.2	1.80	0.816	23.68	10.74	0.12	0.054	1.39	0.63		
	Approach	521.0	236.3	9.53	4.32	3.59	1.63	1.51	0.685	0.52	0.24		
CJ 610-2C GE TJ	Idle	510.0	231.3	79.05	35.86	0.46	0.209	9.18	4.16	0.51	0.23		
	Takeoff	2780.0	1261.0	75.06	34.05	11.68	5.30	0.28	0.127	2.78	1.26		
	Climbout	2430.0	1102.0	65.61	29.76	8.99	4.08	0.49	0.222	2.43	1.10		
	Approach	1025.0	464.9	90.20	40.91	1.54	0.698	2.77	1.26	1.03	0.46		
CF700-2D GE TF	Idle	460	208.7	71.30	32.34	0.41	0.186	8.28	3.76	0.46	0.21		
	Takeoff	2607	1182	57.35	26.01	14.60	6.62	0.26	0.118	2.61	1.18		
	Climbout	2322	1053	58.05	26.33	9.98	4.53	0.23	0.104	2.32	1.05		
	Approach	919	416.9	56.98	25.85	1.65	0.748	1.29	0.585	0.92	0.42		
CF6-6D GE TF	Idle	1063	482.2	65.06	29.51	4.88	2.21	21.79	9.88	1.06	0.48	0.04[g]	0.02[g]
	Takeoff	13750	6237	8.25	3.74	467.5	212.1	8.25	3.74	13.75	6.24	0.54	0.24
	Climbout	11329	5139	6.80	3.03	309.2	140.2	6.80	3.08	11.33	5.14	0.54	0.24
	Approach	3864	1753	23.18	10.51	41.54	18.84	6.96	3.16	3.86	1.75	0.44	0.20
CF6-50C GE TF	Idle	1206	547	88.04	39.93	3.02	1.37	36.18	16.41	1.21	0.55	(Assume CF6-6D data)	
	Takeoff	18900	8573	0.38	0.172	670.95	304.3	0.19	0.086	18.90	8.57		
	Climbout	15622	7104	4.70	2.13	462.0	209.6	0.16	0.073	15.62	7.10		
	Approach	5280	2395	22.70	10.30	52.8	23.95	0.05	0.023	5.28	2.40		

TABLE B.1-7 (CONTINUED)

Model-Series Mfg[b] Type[b]	Mode	Fuel Rate lb/hr	Fuel Rate kg/hr	CO lb/hr	CO kg/hr	NO_x[c] lb/hr	NO_x[c] kg/hr	Total HC[d] lb/hr	Total HC[d] kg/hr	SO_x[e] lb/hr	SO_x[e] kg/hr	Solid Particulates[f] lb/hr	Solid Particulates[f] kg/hr
JT3D-7 P&W TF	Idle	1013	459.5	140.8	63.87	2.23	1.01	124.6	56.52	1.01	0.46	0.45[g]	0.20[g]
	Takeoff	9956	4516	8.96	4.06	126.4	57.34	4.98	2.26	9.96	4.52	8.25	3.7
	Climbout	8188	3714	15.56	7.06	78.6	35.65	3.28	1.49	8.19	3.71	8.5	3.9
	Approach	3084	1399	60.14	27.28	16.35	7.42	6.48	2.94	3.08	1.40	8.0	3.6
JT8D-17 P&W TF	Idle	1150	521.6	39.10	17.74	3.91	1.77	10.10	4.58	1.15	0.52	0.36[g,h]	0.16[g,h]
	Takeoff	9980	4527	6.99	3.17	202.6	91.90	.50	0.227	9.98	4.53	3.7	1.7
	Climbout	7910	3588	7.91	3.59	123.4	55.97	.40	0.181	7.91	3.59	2.6	1.2
	Approach	2810	1275	20.23	9.18	19.39	8.80	1.41	0.640	2.81	1.28	1.5	0.68
JT9D-7 P&W TF	Idle	1849	838.7	142.4	64.59	5.73	2.60	55.10	24.99	1.85	0.84	2.2[f]	1.0
	Takeoff	16142	7322	3.23	1.47	474.6	215.3	0.81	0.367	16.14	7.32	3.75	1.7
	Climbout	13193	5984	6.60	2.99	282.3	128.0	1.32	0.599	13.19	5.98	4.0	1.8
	Approach	4648	2108	44.62	20.24	36.25	16.44	4.65	2.11	4.65	2.11	2.3	1.0
JT9D-70 P&W TF	Idle	1800	816.5	61.20	27.76	5.76	2.61	12.24	0.55	1.80	0.82	(assume JT9D-7 data)	
	Takeoff	19380	8791	3.88	1.76	600.8	272.5	2.91	1.32	19.38	8.79		
	Climbout	15980	7248	4.79	2.17	386.7	175.4	2.40	1.09	15.98	7.25		
	Approach	5850	2654	7.61	3.45	47.39	21.50	2.63	1.19	5.85	2.65		
JT15D-1 PWC TF	Idle	215	97.52	19.46	8.83	0.54	0.245	7.48	3.39	0.22	0.10		
	Takeoff	1405	637.3	1.41	0.640	14.19	6.44	0	0	1.41	0.64		
	Climbout	1247	565.6	1.25	0.567	11.35	5.15	0	0	1.25	0.57		
	Approach	481	218.2	11.45	5.19	2.45	1.11	1.59	0.721	0.48	0.22		
PT6A-27 PWC TP	Idle	115	52.16	7.36	3.34	0.28	0.127	5.77	2.62	0.12	0.05		
	Takeoff	425	192.8	0.43	0.195	3.32	1.51	0	0	0.43	0.19		
	Climbout	400	181.4	0.48	0.218	2.80	1.27	0	0	0.40	0.18		
	Approach	215	97.52	4.95	2.24	1.80	0.816	0.47	0.213	0.22	0.10		
PT6A-41 PWC TP	Idle	147	66.63	16.95	7.69	0.29	0.132	14.94	6.78	0.15	0.07		
	Takeoff	510	231.3	2.60	1.18	4.07	1.85	0.89	0.404	0.51	0.23		
	Climbout	473	214.6	3.07	1.39	3.58	1.62	0.96	0.435	0.47	0.21		
	Approach	273	123.8	9.50	4.31	1.27	0.576	6.20	2.81	0.27	0.12		
Spey 555-15[i] RR TF	Idle	915	415	83.2	37.7	1.6	0.7	86.0	43.5	0.92	0.42		
	Takeoff	5734	2600	6.5	3.0	109.2	49.5	29.5	13.4	5.73	2.60		
	Climbout	4677	2121	0.0	0.0	68.7	31.2	2.5	1.1	4.68	2.12		
	Approach	1744	791	34.8	15.8	10.2	4.6	14.3	6.5	1.74	0.79		
Spey MK511[g,i] RR TF	Idle	946	429.1	104.4	47.36	0.785	0.356	80.03	36.30	0.95	0.43	0.17	0.077
	Takeoff	7057	3201	16.16	7.33	156.7	71.08	13.97	6.34	7.06	3.20	16.0	7.3
	Climbout	5752	2609	0.0	0.0	116.8	52.98	0.0	0.0	5.75	2.61	10.0	4.5
	Approach	2204	999.7	48.71	22.09	16.00	7.26	20.56	9.33	2.20	1.00	1.5	0.68
M45H-01[i] RR (Bristol) TF	Idle	366	166.0	55.63	25.23	0.622	0.282	11.53	5.23	0.37	0.17		
	Takeoff	3590	1628	7.18	3.26	32.31	14.66	0.718	0.326	3.59	1.62		
	Climbout	3160	1433	9.48	4.30	25.28	11.47	0.632	0.287	3.16	1.43		
	Approach	1067	484.0	53.56	24.29	3.57	1.62	6.61	3.00	1.07	0.48		

TABLE B.1-7 (CONTINUED)

Model-Series Mfg.[b] Type[b]	Mode	Fuel Rate lb/hr	Fuel Rate kg/hr	CO lb/hr	CO kg/hr	NO_x^c lb/hr	NO_x^c kg/hr	Total HC[d] lb/hr	Total HC[d] kg/hr	SO_x^e lb/hr	SO_x^e kg/hr	Solid Particulates[f] lb/hr	Solid Particulates[f] kg/hr
RB-211-22B[i]	Idle	1718	779.3	137.6	64.42	5.31	2.41	100.1	45.36	1.72	0.78		
RR TF	Takeoff	14791	6709	5.62	2.55	504.1	228.7	29.14	13.22	14.79	6.71		
	Climbout	12205	5536	14.89	6.75	301.9	136.9	8.30	3.76	12.21	5.54		
	Approach	4376	1985	93.78	42.54	32.26	14.63	32.16	14.59	4.38	1.99		
RB-211-524[i]	Idle	1769	802.4	35.91	16.29	4.74	2.15	5.43	2.46	1.77	0.80		
RR TF	Takeoff	17849	8096	7.32	3.32	660.4	299.6	1.96	0.889	17.85	8.10		
	Climbout	14688	6662	7.34	3.33	470.0	213.2	2.50	1.13	14.69	6.67		
	Approach	5450	2472	11.72	5.32	62.89	28.53	0.545	0.247	5.45	2.47		
RB-401-06[i]	Idle	330	149.7	10.07	4.57	0.825	0.374	0.924	0.419	0.33	0.15		
RR TF	Takeoff	2400	1089	2.40	1.09	30.0	13.61	0.120	0.054	2.40	1.09		
	Climbout	2130	966.2	2.77	1.26	24.07	10.92	0.107	0.049	2.13	0.97		
	Approach	775	351.5	5.04	2.29	3.88	1.76	0.155	0.070	0.78	0.35		
Dart RDa7[i]	Idle	411	186.4	37.61	17.06	0.292	0.132	25.52	11.58	0.41	0.19		
RR TP	Takeoff	1409	639.1	4.79	2.17	8.51	3.86	8.75	3.97	1.41	0.64		
	Climbout	1248	566.1	4.26	1.93	5.55	2.52	2.15	0.975	1.25	0.57		
	Approach	645	292.6	21.48	9.74	0.568	0.258	0.0	0.0	0.65	0.29		
Tyne[g,i]	Idle	619	280.8	40.79	18.50	0.477	0.216	6.63	3.01	0.62	0.28		
RR TP	Takeoff	2372	1076	1.21	0.549	27.11	12.30	2.87	1.31	2.37	1.08		
	Climbout	2188	922.5	1.29	0.585	25.23	11.44	2.63	1.19	2.19	0.99		
	Approach	1095	496.7	11.30	5.13	9.00	4.08	2.68	1.22	1.10	0.50		
Olympus 593[i]	Idle	3060	1388	342.7	155.4	9.72	4.41	119.3	54.11	3.06	1.39		
MK610	Takeoff	52200	23673	1513.8	686.5	542.9	246.2	151.4	68.7	52.2	23.7		
RR (Bristol)	Climbout	19700	8936	275.8	125.1	169.4	76.84	31.52	14.30	19.70	8.94		
TJ	Descent	5400	2449	426.6	193.5	18.9	8.6	132.3	60.0	5.4	2.4		
	Approach	9821	4455	451.8	204.9	41.25	18.71	93.30	42.32	9.82	4.46		
0-200	Idle	8.24	3.75	5.31	2.42	0.013	0.006	0.239	0.107	0.0	0		
Con. O	Takeoff	45.17	20.53	44.0	20.0	0.220	0.100	0.940	0.427	0.01	0		
	Climbout	45.17	20.53	44.0	20.0	0.220	0.100	0.940	0.427	0.01	0		
	Approach	25.50	11.59	30.29	13.75	0.029	0.013	0.847	0.385	0.01	0		
TSIO-360C	Idle	11.5	5.21	6.81	3.09	0.022	0.009	1.59	0.723	0.0	0.0		
Con. O	Takeoff	133.	60.3	143.9	65.3	0.36	0.16	1.22	0.55	0.03	0.01		
	Climbout	99.5	45.1	95.6	43.4	0.43	0.20	0.95	0.43	0.02	0.01		
	Approach	61.0	27.7	60.7	27.5	0.23	0.10	0.69	0.31	0.01	0.01		
6-285-B	Idle	72.12	10.03	26.23	11.90	0.0334	0.0152	0.773	0.350	0.0	0.0		
(Tiara)	Takeoff	153.0	69.39	152.7	69.3	0.899	0.408	1.78	0.806	0.03	0.01		
Con. O	Climbout	166.0	52.61	110.9	50.3	0.913	0.414	1.39	0.632	0.02	0.01		
	Approach	83.5	37.88	85.39	38.77	0.394	0.179	1.343	0.609	0.02	0.01		

TABLE B.1-7 (CONCLUDED)

Model-Series Mfg.[b] Type[b]	Mode	Fuel Rate lb/hr	Fuel Rate kg/hr	CO lb/hr	CO kg/hr	NO_x[c] lb/hr	NO_x[c] kg/hr	Total HC[d] lb/hr	Total HC[d] kg/hr	SO_x[e] lb/hr	SO_x[e] kg/hr	Solid Particulate[f] lb/hr	Solid Particulate[f] kg/hr
O-320	Idle	9.48	4.30	10.21	4.63	0.0049	0.0022	0.350	0.159	0.0	0.0		
Lyc. O	Takeoff	89.1	40.4	96.0	43.5	0.195	0.088	1.05	0.475	0.02	0.01		
	Climbout	66.7	30.3	66.0	29.9	0.265	0.120	0.826	0.375	0.01	0.01		
	Approach	46.5	21.1	56.8	25.8	0.044	0.020	0.895	0.406	0.01	0.0		
IO-320-DIAD	Idle	7.84	3.56	4.86	2.20	0.009	0.0041	0.283	0.128	0.0	0.0		
Lyc. O	Takeoff	91.67	41.57	109.3	49.55	0.167	0.0756	1.047	0.475	0.02	0.01		
	Climbout	61.42	27.85	54.55	24.74	0.344	0.156	0.588	0.267	0.01	0.01		
	Approach	37.67	17.08	35.57	16.13	0.128	0.058	0.460	0.208	0.01	0.0		
IO-360-B	Idle	8.09	3.68	7.26	3.29	0.0094	0.0042	0.398	0.180	0.0	0.0		
Lyc. O	Takeoff	103.0	46.7	123.5	56.0	0.205	0.093	1.03	0.469	0.02	0.01		
	Climbout	71.7	32.5	70.5	32.0	0.329	0.149	0.585	0.265	0.01	0.01		
	Approach	36.6	16.6	25.3	11.5	0.372	0.169	0.355	0.161	0.01	0.0		
TIO-540-J2B2	Idle	25.06	11.36	32.42	14.70	0.0097	0.0044	1.706	0.774	0.01	0.0		
Lyc. O	Takeoff	259.7	117.8	374.5	169.8	0.094	0.043	3.21	1.46	0.05	0.02		
	Climbout	204.5	92.7	300.8	136.4	0.0481	0.0218	3.40	1.54	0.04	0.02		
	Approach	99.4	45.1	125.4	56.9	0.138	0.0623	1.33	0.604	0.02	0.01		

[a] Refs. 1, 2.

[b] Abbreviations: All — Detroit Diesel Allison Division of General Motors; Con — Teledyne/Continental; GA — Garrett AiResearch; GE — General Electric; Lyc — Avco/Lycoming; P&W — Pratt & Whitney; PWC — Pratt & Whitney Aircraft of Canada; RR — Rolls Royce; TJ — Turbojet; TF — Turbofan ("fanjet"); TP — Turboprop; O — Reciprocating (Piston) Opposed.

[c] Nitrogen oxides reported as NO_2.

[d] Total hydrocarbons. Includes unburned hydrocarbons and organic pyrolysis products.

[e] Sulfur oxides and sulfuric acid reported as SO_2. Calculated from fuel rate and 0.05 wt% sulfur in Jet A and Jet B fuel, or 0.01 wt% sulfur in aviation gasoline. For turbine engines, the conversion is therefore SO_x (lb/hr) = 10^{-3} (fuel rate), and for piston engines, the conversion is SO_x (lb/hr) = 2×10^{-4} (fuel rate).

[f] All particulate data are from Ref. 4.

[g] The indicated reference does not specify series number for this model engine.

[h] "Diluted smokeless" JT 8D. Note: JT8D is a turbofan engine and is not equivalent to the JT8 (Military J52) turbojet engine.

[i] All Rolls Royce data are based upon an arbitrary 7% idle which does not reflect the actual situation. In reality, Rolls Royce engines will idle at 5-6% with correspondingly higher emissions (Ref. 20).

[j] The Olympus 593 engine is used in the Concorde SST, which has a unique 6-mode LTO cycle.

TABLE B.1-8. MODAL EMISSION RATES – MILITARY AIRCRAFT ENGINES[a]

Model-Series (Civil Version) Mfg[h] Type[h]	Mode	Fuel Rate		CO		NO_x[b]		Total HC[c]		SO_x[d]		Particulates[e,f]	
		lb/hr	kg/hr	lb/hr	kg/hr	lb/hr	kg/hr	lb/hr	kg/hr	lb/hr	kg/hr	lb/hr	kg/hr
J57-P-22 (JT3C) P&W TJ	Idle	1087	493	64.4	29.2	2.7	1.2	55.8	25.3	1.1	0.5	8.3	3.8
	Takeoff	8358	3791	14.9	6.8	93.3	42.3	5.4	2.4	8.4	3.8	12.0	5.4
	Climbout	8358	3791	14.9	6.8	93.3	42.3	5.4	2.4	8.4	3.8	12.0	5.4
	Approach	1693	768	39.8	18.1	5.0	2.3	21.0	9.5	1.7	0.8		
J65-W-20 Wr. TJ	Idle	1333	605	66.9	30.3	3.7	1.7	5.0	2.3	1.3	0.6		
	Takeoff	6421	2913	49.6	22.5	48.5	22.0	0.2	0.1	6.4	2.9		
	Climbout	6421	2913	49.6	22.5	48.5	22.0	0.2	0.1	6.4	2.9		
	Approach	3260	1479	52.6	23.9	23.7	10.8	0.9	0.4	3.3	1.5		
J79-GE-10 GE TJ	Idle	1100	499	48.0	21.8	3.2	1.5	9.8	4.4	1.1	0.5	57.8	26.2
	Takeoff	35390	16053	611.9	277.6	241.3	109.5	17.2	7.8	35.4	16.1	299.7	135.9
	Climbout	9680	4482	52.0	23.6	151.8	68.9	16.0	7.3	9.9	4.5	77.7	35.2
	Approach	6190	2808	45.6	20.7	69.9	31.7	4.1	1.9	6.2	2.8	67.0 (nom)	30.4
J85-GE-5F GE TJ for T38	Idle	524	328	93.3	42.3	0.7	0.3	15.7	7.1	0.5	0.2		
	Takeoff	8470	3942	245.6	111.4	22.0	10.0	6.8	3.1	8.5	3.9		
	Climbout	1297	588	55.8	25.3	3.0	1.4	4.5	2.0	1.3	0.6		
	Approach	1098	498	63.7	28.9	3.0	1.4	1.3	0.6	1.1	0.5		
J85-GE-21 GE TJ for F-5	Idle	400	181	63.6	28.4	0.5	0.2	9.7	4.4	0.4	0.2		
	Takeoff	10650	4831	387.7	175.8	59.6	27.0	1.1	0.5	10.7	4.9		
	Climbout	3200	1452	69.0	31.3	16.0	7.3	0.8	0.4	3.2	1.5		
	Approach	1200	544	55.5	25.1	3.5	1.6	3.1	1.4	1.2	0.5		
TF30-P-6B (JFT 10) P&W TF for A-7	Idle	689	313	47.0	21.3	0.9	0.4	12.9	5.9	0.7	0.3		
	Takeoff	6835	3100	21.1	9.6	82.3	37.3	6.9	3.1	6.8	3.1		
	Climbout	6835	3100	21.1	9.6	82.3	37.3	6.9	3.1	6.8	3.1		
	Approach	3550	1610	22.4	10.2	23.7	10.8	10.5	4.8	3.6	1.6		
TF30-P-412A (JFT 10A) P&W TJ for F-14	Idle	999	453	68.1	30.9	2.4	1.1	38.4	17.4	1.0	0.5	26.5	12.0
	Takeoff	40000	18144	600.0	272.2	270.0	122.5	40.0	18.1	40.0	18.1	693.2	314.4
	Climbout	7394	3354	15.7	7.1	123.2	55.9	0.7	0.3	7.4	3.4	61.7	29.0
	Approach	2598	1178	39.5	17.9	18.4	8.3	2.9	1.3	2.6	1.2	46.6 (nom)	21.2
TF33-P-3/5/7 (JT3D) P&W TJ	Idle	846	384	74.9	34.0	1.5	0.7	77.8	35.3	0.8	0.4	4.4	2.0
	Takeoff	9979	4526	13.0	5.9	109.8	49.8	3.0	1.4	10.0	4.5	79.8	36.2
	Climbout	7323	3322	13.2	6.0	65.9	29.9	2.9	1.3	7.3	3.3	102.5	46.5
	Approach	3797	1722	34.2	15.5	27.7	12.6	14.4	6.5	3.8	1.7	53.1	24.1
TF34-GE-400 GE TJ	Idle	457	207	35.0	15.9	0.6	0.3	7.1	3.2	0.5	0.2		
	Takeoff	3796	1722	9.3	4.2	20.9	9.5	1.6	0.7	3.8	1.7		
	Climbout	3796	1722	9.3	4.2	20.9	9.5	1.6	0.7	3.8	1.7		
	Approach	1296	588	19.4	8.8	10.0	4.5	0.8	0.4	1.3	0.6		

TABLE B.1-8 (CONCLUDED)

Model-Series (Civil-Version) Mfg[h] Type[h]	Mode	Fuel Rate lb/hr	Fuel Rate kg/hr	CO lb/hr	CO kg/hr	NO[b] lb/hr	NO[b] kg/hr	Total HC[c] lb/hr	Total HC[c] kg/hr	SO_x[d] lb/hr	SO_x[d] kg/hr	Particulates[e, f] lb/hr	Particulates[e, f] kg/hr
TF39-GE-1	Idle	1130	513	75.7	34.3	3.4	1.5	26.0	11.8	1.1	0.5	0.3[g]	0.1
(JT4A)	Takeoff	11410	5176	8.0	3.6	319.5	144.9	2.3	1.0	11.4	5.2	17.1[g]	7.8
GE TJ	Climbout	5740	2604	4.0	1.8	160.7	72.9	1.1	0.5	5.7	2.6	8.0[g]	3.6
	Approach	5740	2604	4.0	1.8	160.7	72.9	1.1	0.5	5.7	2.6	8.0[g]	3.6
TF41-A-2	Idle	1070	485	114.6	52.0	1.4	0.6	70.8	32.1	1.1	0.5		
All. TF	Takeoff	9040	4101	14.4	6.5	201.4	91.4	5 3	2.4	9.0	4.1		
	Climbout	9040	4101	14.4	6.5	201.4	91.4	5.3	2.4	9.0	4.1		
	Approach	5314	2410	27.5	12.5	56.6	25.7	12.9	5.9	5.3	2.4		
F100-PW-100	Idle	1060	481	20.5	9.3	4.2	1.9	2.4	1.1	1.1	0.5	0.1[g]	0.05
(JTF 22)	Takeoff	44200	20049	2435.4	1104.7	729.3	330.8	4.4	2.0	44.2	20.0	0.0[g]	0.0
P&W TF	Climbout	10400	4717	18.7	8.5	457.6	207.6	0.5	0.2	10.4	4.7	8.6[g]	3.9
	Approach	3000	1361	9.0	4.1	33.0	15.0	1.8	0.8	3.0	1.4	1.0[g]	0.5
PT6A-27	Idle	115	52	7.36	3.34	0.28	0.13	5.77	2.62	0.12	0.05		
PWC TP	Takeoff	425	193	0.43	0.20	3.32	1.51	0	0	0.43	0.20		
	Climbout	400	181	0.48	0.22	2.80	1.27	0	0	0.40	0.18		
	Approach	215	98	5.0	2.24	1.80	0.82	0.47	0.21	0.22	0.10		
T56-A7	Idle	548	249	17.5	7.9	2.1	1.0	11.5	5.2	0.5	0.2	1.6	0.7
All. TP	Takeoff	2079	943	4.4	2.0	19.3	8.8	0.8	0.4	2.1	1.0	3.7	1.7
	Climbout	1908	865	4.6	2.1	17.6	8.0	0.9	0.4	0.9	0.4	3.0	1.4
	Approach	1053	478	3.7	1.7	7.8	3.5	0.5	0.2	1.1	0.5	3.0	1.4
T53-L-11D	Idle	142	64	4.2	1.9	0.2	0.1	9.0	4.1	0.14	0.06		
(LTC1)	Climbout[i]	679	308	2.0	0.9	5.0	2.3	0.2	0.1	0.68	0.31		
Lyc TS	Approach	679	308	2.0	0.9	5.0	2.3	0.2	0.1	0.68	0.31		
T55-L-11A	Idle			29.5	13.4	0.8	4.0	4.0	1.8				
(LTC4)	Climbout[i]			14.5	6.6	18.6	8.4	0.2	0.1				
Lyc TS	Approach			12.9	5.9	9.1	4.1	0.3	0.1				
T58-GE-5	Idle	133	60	22.5	10.2	0.2	0.1	12.9	5.9	0.1	0.05	0.1	0.05
GE TS	Climbout[i]	886	402	5.0	2.3	6.4	2.9	0.7	0.3	0.9	0.4	0.8	0.4
	Approach	886	402	5.0	2.3	6.4	2.9	0.7	0.3	0.9	0.4	0.8	0.4

[a] Ref. 1.

[b] Nitrogen oxides reported as NO_2.

[c] Hydrocarbons (volatile organics). Includes unburned hydrocarbons, and organic pyrolysis products.

[d] Sulfur oxides and sulfuric acid reported as SO_2. Calculated from fuel rate and 0.05 wt% sulfur in JP-4 or JP-5 fuel, or 0.01 wt% sulfur in aviation gasoline. For turbine engines, the conversion is therefore SO_x (lb/hr) = 10^{-3} (fuel rate), and for piston engines, the conversion is SO_x (lb/hr) = 2×10^{-4} (fuel rate).

[e] Includes all "condensible particulates," and, thus may be much higher than solid particulates alone (except as noted in g below).

[f] "Nom." data are interpolated values assumed for calculational purposes, in the absence of experimental data.

[g] Dry particles only.

[h] For abbreviations, cf., footnote, Table B.1-2.

[i] "Takeoff" mode is underfined for helicopters.

TABLE B.1-9. EMISSION FACTORS PER AIRCRAFT PER LANDING-TAKEOFF CYCLE – CIVIL AIRCRAFT[a]

Commercial Carrier Aircraft	Power Plant[b]			CO		NO_x[c]		Total HC[d]		SO_x[e]		Particulates	
	No.	Mfg.	Model-Series	lb	kg	lb	kg	lb	kg	lb	kg	lb	kg
Short, Medium, Long Range and Jumbo Jets													
BAC/Aerospatiale Concorde	4	RR	Olymp 593	847.0	384.0	91.0	41.0	246.0	112.0	14.1	6.4		
BAC 111-400	2	RR	Spey 511	103.36	46.88	15.04	6.82	72.42	32.85	1.70	0.77	1.46	0.66
Boeing 707-320B	4	P&W	JT3D-7	262.64	119.12	25.68	11.64	218.24	99.00	4.28	1.94	4.52	2.05
Boeing 727-200	3	P&W	JT8D-17	55.95	25.38	29.64	13.44	13.44	6.09	3.27	1.48	1.17	0.53
Boeing 737-200	2	P&W	JT8D-17	37.30	16.92	19.76	8.96	8.96	4.06	2.18	0.99	0.78	0.35
Boeing 747-200B	4	P&W	JT9D-7	259.64	117.76	83.24	37.76	96.92	43.96	7.16	3.25	5.20	2.36
Boeing 747-200B	4	P&W	JT9D-70	108.92	49.40	107.48	48.76	22.40	10.16	7.96	3.61	5.20	2.36
Boeing 747-200B	4	RR	RB211-524	66.76	30.28	124.9	56.65	10.00	4.54	7.52	3.41		
Lockheed L1011-200	3	RR	RB211-524	50.07	27.71	93.66	42.48	7.50	3.40	5.64	2.56		
Lockheed L1011-100	3	RR	RB211-22B	199.4	90.44	64.29	29.16	138.4	62.77	4.95	2.24		
McDonnell-Douglas DC8-63	4	P&W	JT3D-7	262.64	119.12	25.68	11.64	218.24	99.00	3.27	1.48	1.17	0.53
McDonnell-Douglas DC9-50	2	P&W	JT8D-17	37.30	16.92	19.76	8.96	8.96	4.06	2.18	0.99	0.78	0.35
McDonnell-Douglas DC10-30	3	GE	CF6-50C	116.88	53.01	49.59	22.17	47.10	21.36	4.98	2.26	0.21	0.10
Air Carrier Turboprops – Commuter, Feeder Line and Freighters													
Beech 99	2	PWC	PT6A-28	7.16	3.25	0.82	0.37	5.08	2.30	0.18	0.08		
GD/Convair 580	2	All	501	24.38	11.06	21.66	9.82	9.82	4.45	0.92	0.42		
DeHavilland Twin Otter	2	PWC	PT6A-27	7.16	3.25	0.82	0.37	5.08	2.30	0.18	0.08		
Fairchild F27 and FH227	2	RR	R.Da.7	36.26	16.45	0.92	0.42	22.42	10.17	0.58	0.26		
Grumman Goose	2	PWC	PT6A-27	7.16	3.25	0.82	0.37	5.08	2.30	0.18	0.08		
Lockheed L188 Electra	4	All	501	48.76	22.12	43.32	19.65	19.64	8.91	1.84	0.83		
Lockheed L100 Hercules	4	All	501	48.76	22.12	43.32	19.65	19.64	8.91	1.84	0.83		
Swearingen Metro-2	2	GA	TPE 331-3	6.26	2.84	1.16	0.53	7.68	3.48	0.16	0.07	0.46	0.21

TABLE B.1-9 (CONCLUDED)

General Aviation Aircraft	Power Plant[b]			CO		NO_x[c]		Total HC[d]		SO_x[e]		Particulates	
	No.	Mfg.	Model-Series	lb	kg	lb	kg	lb	kg	lb	kg	lb	kg
<u>Business Jets</u>													
Cessna Citation	2	P&W	JT15D-1	19.50	8.85	2.00	0.91	6.72	3.05	0.40	0.18		
Dassault Falcon 20	2	GE	CF700-2D	76.14	34.54	1.68	0.76	7.40	3.36	0.78	0.35		
Gates Learjet 24D	2	GE	CJ610-6	88.76	40.26	1.58	0.72	8.42	3.82	0.84	0.38		
Gates Learjet 35, 36	2	GE	TPE 731-2	11.26	5.11	3.74	1.58	3.74	1.70	0.92	0.42		
Rockwell International Shoreliner 75A	2	GE	CF 700	76.14	34.54	1.08	0.76	7.40	3.36	0.78	0.35		
<u>Business Turboprops (EPA Class P2)</u>													
Beech B99 Airliner	2	PWC	PT6A-27	7.16	3.25	0.82	0.37	5.08	2.30	0.18	0.08		
DeHavilland Twin Otter	2	PWC	PT6A-27	7.16	3.25	0.82	0.37	5.08	2.30	0.18	0.08		
Shorts Skyvan-3	2	GA	TPE-331-2	6.44	2.92	0.883	0.400	8.40	3.81	0.16	0.07	0.46	0.21
Swearingen Merlin IIIA	2	GA	TPE-331-3	6.28	2.85	1.15	0.522	7.71	3.50	0.16	0.07	0.46	0.21
<u>General Aviation Piston (EPA Class P1)</u>													
Cessna 150	1	Con	0-200	8.32	3.77	0.02	0.01	0.23	0.10	0.0	0.0		
Piper Warrior	1	Lyc	0-320	14.37	6.52	0.02	0.01	0.26	0.12	0.0	0.0		
Cessna Pressurized Skymaster	2	Con	TS10-360C	33.10	15.01	0.13	0.06	1.15	0.52	0.0	0.0		
Piper Navajo Chieftain	2	Lyc	T10-540	96.24	43.65	0.02	0.01	1.76	0.80	0.0	0.0		

[a]Ref. 2.

[b]Abbreviations: All – Detroit Diesel Allison Division of General Motors; Con – Teledyne/Continental; GA – Garrett AiResearch; GE – General Electric; Lyc – Avco/Lycoming; P&W – Pratt & Whitney; PWC – Pratt & Whitney Aircraft of Canada; RR – Rolls Royce.

[c]Nitrogen oxides reported as NO_2.

[d]Total hydrocarbons (volatile organics, including unburned hydrocarbons and organic pyrolysis products.)

[e]Sulfur oxides and sulfuric acid reported as SO_2.

TABLE B.1-10. EMISSION FACTORS PER AIRCRAFT LANDING-TAKEOFF CYCLE – MILITARY AIRCRAFT[a]

Aircraft		Power Plant		TIM[b]	Emissions per LTO Cycle									
					CO		NO_x[c]		Total HC[d]		SO_x[e]		Particulates	
DOD Desig.	Popular Name	No.	Model - Series	Code	lb	kg	lb	kg	lb	kg	lb	kg	lb	kg
Fixed Wing – Turbine														
A-4C	Skyhawk	1	J65-W-20	2	16.62	7.54	2.15	0.98	1.10	0.50	0.46	0.21		
A-7	Corsair 2	1	TF30-P-6B	2	11.10	5.03	2.05	0.93	3.18	1.44	0.35	0.16		
A-7	Corsair 2	1	TF41-A-2	2	25.79	11.70	4.83	2.19	15.76	7.15	0.52	0.24		
B-52H	Stratofortress	8	TF-33-P-3/5/8	7	504.08	228.65	53.04	24.06	505.76	229.41	10.24	4.64	94.08	42.67
F-4	Phantom 2	2	J79-GE-10	2	32.24	14.62	10.88	4.94	4.94	2.24	1.46	0.66	33.92	15.39
F-5	Freedom Fighter/ Tiger 2	2	J85-GE-21	1	76.64	34.76	2.10	0.95	10.04	4.55	0.76	0.34		
F-14	Tomcat	2	TF30-P-412A	2	39.88	18.09	7.62	3.46	17.36	7.87	1.24	0.56	24.24	11.00
F-15A	Eagle	2	F100-PW-100	1	54.40	24.68	29.96	13.58	2.68	1.22	2.32	1.06	0.44	0.20
F-16	------------	1	F100-PW-100	1	27.20	12.34	14.98	6.79	1.34	0.61	1.16	0.53	0.22	0.10
C-5A	Galaxy	4	TF39-GE-1	5	82.12	37.25	79.60	36.11	28.08	12.74	3.84	1.74	4.12	1.87
C-130	Hercules	4	T56-A-7	6	32.36	14.68	9.60	4.35	20.28	9.20	1.60	0.73	4.36	1.98
KC-135	Stratotanker	4	J57-P-22	7	220.92	100.21	24.64	11.18	185.56	84.17	5.36	2.43	31.36	14.22
C-141	Starlifter	4	TF33-P-3/5/7	5	92.40	41.91	19.20	8.71	87.68	39.77	3.00	1.36	33.00	14.97
T-34C	Turbo Mentor	1	PT6A-27	2	1.73	0.78	0.15	0.07	1.27	0.58	0.03	0.01		
T-38	Talon	2	J85-GE-5F	3	82.72	32.99	1.22	0.55	10.42	4.73	0.62	0.82		
P-3C	Orion	4	T56-A-7	6	32.36	14.68	9.60	4.35	20.28	9.20	1.60	0.73	4.36	1.98
S-3A	Viking	2	TF34-GE-400	6	34.18	15.50	4.04	1.83	6.44	2.92	1.02	0.46		
Helicopters – Turbine														
UH-1H	Iroquois/Huey	1	T53-L-11D	9	1.55	0.70	1.19	0.54	2.53	1.15	0.20	0.09		
HH-3	Sea King/Jolly Green Giant	2	T58-GE-5	9	13.54	6.14	3.02	1.37	6.78	3.08	0.44	0.20	0.40	0.18
CH-47	Chinook	2	T55-L-11A	9	20.94	9.50	6.68	3.03	2.10	0.96				

[a] Ref. 1.

[b] The TIM code is defined in Table B.1-4.

[c] Nitrogen oxides reported as NO_2.

[d] "Total hydrocarbons" (volatile organics). Includes unburned hydrocarbons and organic pyrolysis products.

[e] Sulfur oxides and sulfuric acid reported as SO_2.

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16. ABSTRACT

Using data supplied by the U.S. Navy, U.S. Air Force, USEPA Office of Mobile Source Air Pollution Control, as well as published information, tables of military aircraft fuel characteristics, aircraft classifications, military and civil times in mode, engine modal emission rates, and aircraft emission factors per landing-takeoff cycle are calculated and compiled. The data encompass 59 engines and 89 aircraft. Additional discussion includes information related to benzo[a]pyrene emissions and to hydrocarbon emissions (volatile organic) with potential to produce photochemical oxidant.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Air Pollution Engines Exhaust Gases Emissions	Emission Factors Environmental Data	13B 21D, E, G

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